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3rd e-VLBI Workshop was held at Makuhari, Japan

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The logo mark of the workshop designed by Shinobu Arimura and Yasuhiro Koyama.

Kashima Space Research Center of the National Institute of Information and Communications Technology (NICT) hosted the 3rd e-VLBI workshop for two days on October 6 and 7, 2004. It became the first international workshop for us to host since our institute was restructured from Communications Research Laboratory (CRL). CRL was merged with the Telecommunications Advancement Organization of Japan and the NICT was established on April 1, 2004.

At the time when the first e-VLBI workshop was help at Haystack Observatory in April 2002, it was determined to hold the workshop once every year. Makuhari Prince Hotel was selected as a venue of the 3rd workshop and 67 people from 13 countries around the world have participated in the workshop. The presentations were broadcasted live over the Internet so that anyone could hear and view the presentations and discussions from anywhere connected to the Internet.

The guest room tower of the hotel is known as the tallest building as a single construction used solely by a hotel in Japan, and the rooms were shaken quite a bit when an earthquake (Richter scale 5.7) occurred at 10 minutes before the midnight on the first day of the workshop. In addition, a strong typhoon passed over the region just after the workshop and it stopped many planes departing from the Narita airport. It was really fortunate that all participants seemed to have returned home without any problem in spite of these natural extremes,

During the workshop, many up-to-date developments in the fields of high speed network research and e-VLBI were given. Researchers from different fields of research like high energy physics and educational research network have also participated in the workshop and presented review talks. As it was pointed out in many presentations, availabilities of the high speed network connections between VLBI observing sites and correlators have been improved dramatically, and many successful demonstrations of e-VLBI have been realized compared with the situation we had at the time of the 1st e-VLBI workshop two years ago. It seems there is no doubt that the series of the e-VLBI workshops have stimulated and promoted the fast and remarkable developments in the field of e-VLBI and in this sense all three workshops can be viewed as extremely successful. Tasso Tzioumis from ATNF, CSIRO proposed to hold the next e-VLBI workshop in Australia and the proposal was warmly welcomed by all participants to the workshop. Since Australia has been very active in the e-VLBI activities recently, it seems promising another successful workshop will be held again next year.

Pictures taken during the workshop.

The 3rd e-VLBI Workshop

Program

October 6 (Wed.)

Session 1 General Review (Chair : Wolfgang Schlüter)

10:00-10:05	Hiroshi Kumagai (NICT) Welcome
10:05-10:25	Fujinobu Takahashi (Yokohama National University) The Study of Sustainable System Design for Global e-VLBI Networks
10:25-10:55	T. Charles Yun (Internet2) e-VLBI and Internet2: Update and Future
10:55-11:25	Stephen M. Parsley (JIVE) eVLBI in Europe, a General Perspective
11:25-11:55	Yasuichi Kitamura (NICT) High performance infrastructure for e-VLBI

Lunch (11:55-13:30)

13:30-14:00	Alan R. Whitney (MIT Haystack Observatory) Real-time e-VLBI Experiments at Haystack Observatory
14:00-14:30	Anastasios K. Tzioumis (ATNF, CSIRO) eVLBI progress in Australia

Session 2 High Speed Data Transfer over the Network (Chair : Stephen M. Parsley)

14:30-14:50	David E. Lapsley (MIT Haystack Observatory) e-VLBI Network and Platform Monitoring
14:50-15:10	Masaki Hirabaru (NICT) Performance Measurement on Large Bandwidth-Delay Product Networks

Break (15:10-15:30)

15:30-16:00	David E. Lapsley (MIT Haystack Observatory) VSI-E Implementation and Results
16:00-16:20	Hiroshi Sakamoto (University of Tokyo, ICEPP) LHC Computing Grid : A Globally Distributed Analysis Infrastructure for High Energy Physics
16:20-16:40	Jun Matsukata (National Institute of Informatics) Thoughts on Information Communication Infrastructure for the Research Educational Network
16:40-17:00	Noriyuki Kawaguchi (NAOJ) The e-VLBI Operations on Three Stations at 2.5-Gbps in Japan

Banquet (18:00-20:00) at "Marine" (Main Tower 4F)

October 7 (Thu.)

Session 3 Reports of Developments and Results (Chair : Jon Romney)

9:00-9:20	Hiroshi Takeuchi (NICT) Ongoing e-VLBI Developments with K5 VLBI System
9:20-9:40	Tetsuro Kondo (NICT) Current status of K5 software correlator
9:40-10:00	David E. Lapsley (MIT Haystack Observatory) Design of Experiment Guided Adaptive Endpoint
10:00-10:20	Yasuhiro Koyama (NICT) Rapid turn around UT1 estimation with e-VLBI

Break (10:20-10:40)

10:40-11:00	Ryuichi Ichikawa (NICT) Throughput Test of Satellite Data Transmission for Space Geodesy using the TCP/IP link in the South Pacific
11:00-11:20	Mamoru Sekido (NICT) Astrometric VLBI observation of Spacecraft with phase delay

Session 4 Future Plans and Regional Status Reports (Chair : Mamoru Sekido, Yasuhiro Koyama)

11:20-11:40	Makoto Miyoshi (NAOJ) A sub-mm VLBI netwrok, Horizon Telescope II
11:40-12:00	Hisashi Hirabayashi (JAXA, ISAS) Space-VLBI after VSOP, RadioAstron Age

Lunch (12:00-13:30), Asia Pacific Telescope (APT) Meeting

13:30-13:50	Hiroshi Sudou (Gifu University) The feasibility and Scientific Goals of the Japanese e-VLBI System
13:50-14:10	Xiuzhong Zhang (Shanghai Astronomical Observatory) The eVLBI in Chinese VLBI Network
14:10-14:30	Zheng Wen Sun (Urumqi Astronomical Observatory) Status of VLBI and e-VLBI in Urumqi Astronomical Observatory
14:30-14:50	Arpad Szomoru (JIVE) Recent eVLBI developments at JIVE

Break (14:50-15:10)

15:10-15:30	Jouko J. Ritakari (Metsähovi Radio Observatory) Recent eVLBI developments at Metsähovi
15:30-15:50	Mauro Nanni (CNR Ist. Radioastronomia) E-vlbi in Italy

Session 5 Discussions (Chair : Alan Whitney)

15:50-16:30	All Participants Discussions
16:30-16:35	Taizoh Yoshino (Mitsubishi Electric Co.) Closing Remarks

Posters

P-1 David E. Lapsley (MIT Haystack Observatory)
Experiences of Upgrading to 2.5 Gbps using DWDM Technology

P-2 David E. Lapsley (MIT Haystack Observatory)
The Application of Cluster Computing to e-VLBI

P-3 Kevin A. Dudevoir (MIT Haystack Observatory)
Mark 5 Network Performance Issues

P-4 Gino Tuccari (IRA - INAF)
E-LFVN - An Internet Based VLBI Network

P-5 Moritaka Kimura (NICT)
High Performance PC based Gigabit VLBI System

P-6 Yasuhiro Murata (JAXA)
Current Status of the Next Generation Space VLBI Mission: VSOP-2

P-7 Yusuke Kono (NAOJ)
Broadband VLBI Data Downlink of VSOP-2

High Performance Infrastructure for e-VLBI

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Abstract

High speed bandwidth data transferring made the real time VLBI in real. And Next Generation Internet Service made the e-VLBI in real. The difference between 2 is if the VLBI stations are opened or not. At the real time VLBI, the stations are inside of the leased lines and it was impossible to access the stations or to increase the new stations for the experiment. At the e-VLBI, the stations are a little bit away from the Internet but, the new stations can join this project freely. In this report, the history both of the Next Generation Internet Service and the real time VLBI are shown, first. The current e-VLBI experiment environment is shown later.

1. Next Generation Internet Service

1.1. My understanding of the Next Generation Internet

The technical term, such as "Next Generation Internet Service", became familiar with researchers just after the word "Internet" became popular. The Internet is the best effort service. It is very easy to use but the QoS is not guaranteed. In general, especially, in Asian area, the word "Next Generation Internet Service" guarantee the high performance data transferring. The bandwidth of the network is the second matter. In the Next Generation Internet, the network is ready for the advanced technology applications. The advanced technology applications are based on the advanced protocols, such as the revised TCP or IPv6. In the western area, it has to support the high bandwidth network and the long distance data transferring.

1.2. Some histories

One of the first Next Generation Internet Service was the very high performance Backbone Network Service(vBNS) which was started by the National Science Foundation(NSF). This network was based on the ATM technology and this network covered all USA area between the east coast and the west coast. The current USA backbone is the Abilene which is managed by University Cooperation for Advanced Internet Development(UCAID). This network is based on the Packet over SONET system and it became one of the backbones of the Internet2. The current bandwidth is 10Gbps. Canada is one of the adventures countries about the Next Generation Internet Services. Canada always implemented the most advanced technology on their backbone. The network name is CA*net with the number. For example, 2, 3 or 4. The actual network is the CA*net4. This is the first lambda switching network. In Europe, this service was operated by DANTE and some institutions. Their first network was TEN-34. After that, it moves to TEN-155 and the current backbone name which covers European area is GEANT. The main connection is in the 10Gbps bandwidth and it keeps the mutual connections of all National Research and Education Networks(NRENs).

1.3. Next Generation Internet Service in Japan

Actually, there are 2 next generation networks in Japan. One is the Science Information Network(SINET) [1]. SINET is opened for universities and national laboratories. Recently, SINET started the new service whose name is Super-SINET. Super-SINET supports the lambda switching. The main backbone is moving to Super-SINET and the link between US and Japan moved to Super-SINET, already.

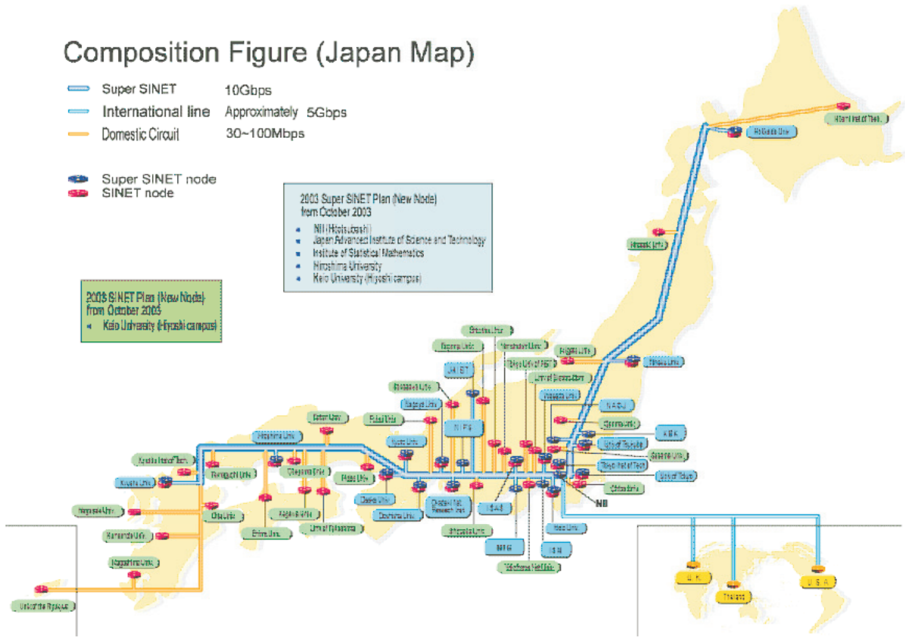

Figure 1. SINET

Another one is JGN II [2]. JGN II is the second generation service of the Japan Gigabit Network. JGN II is opened for universities, national laboratories and none-profit organizations. JGN II is based on the lambda switching technologies and the main links are in 10Gbps bandwidth. Actually, the Kashima VLBI station is connected with this JGNII.

1.4. Asia-Pacific Advanced Network (APAN)

APAN [3] is the research and education consortium since 1997. The name of APAN includes "Network" but APAN itself does not manage the network. But, APAN organizes the research and education networks in Asian and Pacific area. APAN has the network operation center(NOC) team and this team handles the interconnection of these R&E networks. The team also has the skill for keeping one of the characteristics of the next generation Internet service. That is QoS.

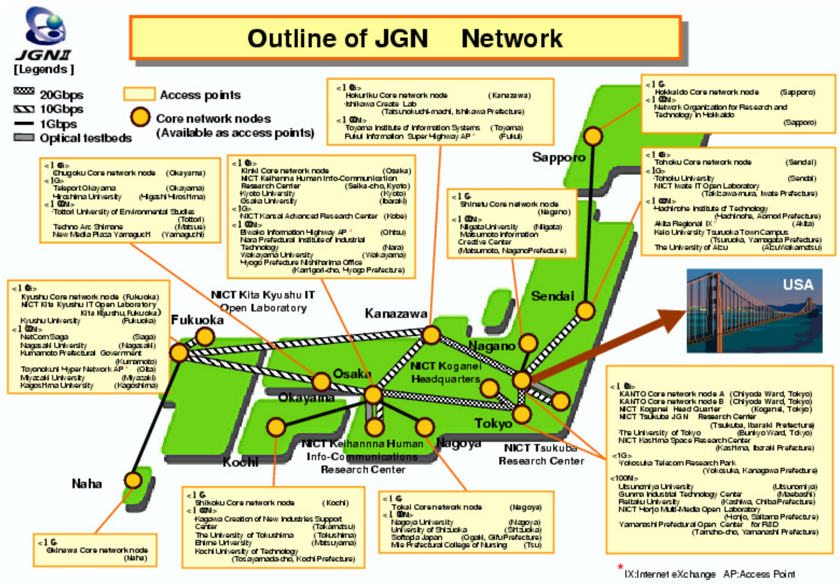

Figure 2. JGNII

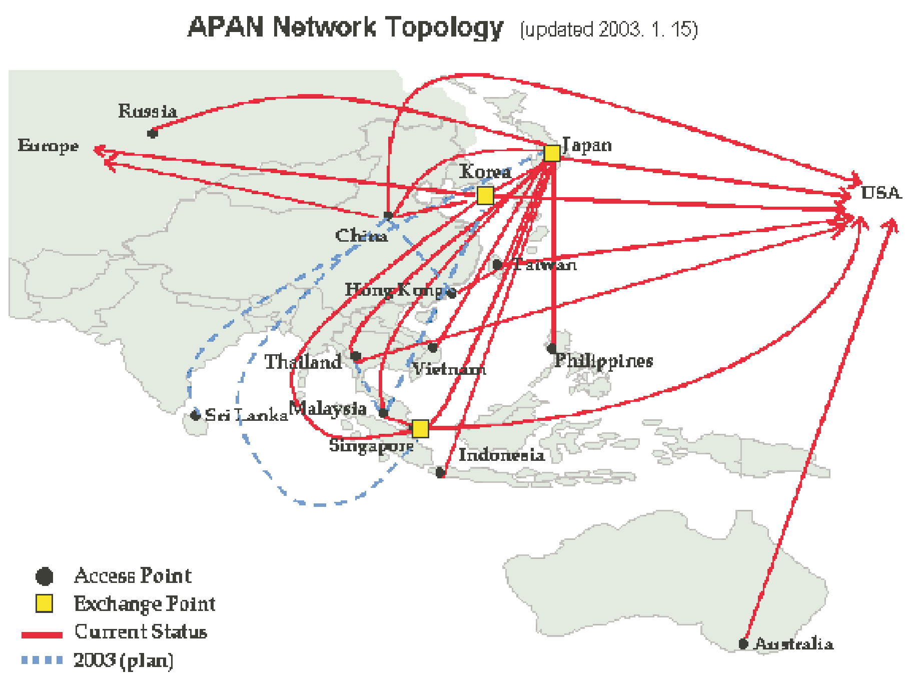

Figure 3. APAN Network

2. e-VLBI activities in Japan, especially about the Kashima station

2.1. Key Stone Project

Key Stone Project was the first e-VLBI type experiment in Japan. In those days, this project was called as "Real time VLBI". This project started in 1994. In 1994, in Japan, there were, at least, 3 R&E networks. Inter Ministry network(IMnet) was the brand new R&E network in those days. It covered universities, national laboratories and none profit organizations. The maximum bandwidth of this network was 45Mbps. SINET was the just reconstructed on the former R&E network. In 2002, SINET started covering the IMnet function, too. Till then, SINET supported just universities and some national laboratories. The maximum bandwidth was 128kbps. Widely Integrated Distributed Environment(WIDE) backbone was the first Internet service in Japan. This covers universities, laboratories and some companies. The maximum bandwidth was 1.5Mbps, and this link was always congested. These R&E networks did not have enough bandwidth for the eVLBI. And, these R&E networks were not ready for keeping the QoS for end users. For such reasons, the leased lines were used for connecting the "Real time VLBI" stations.

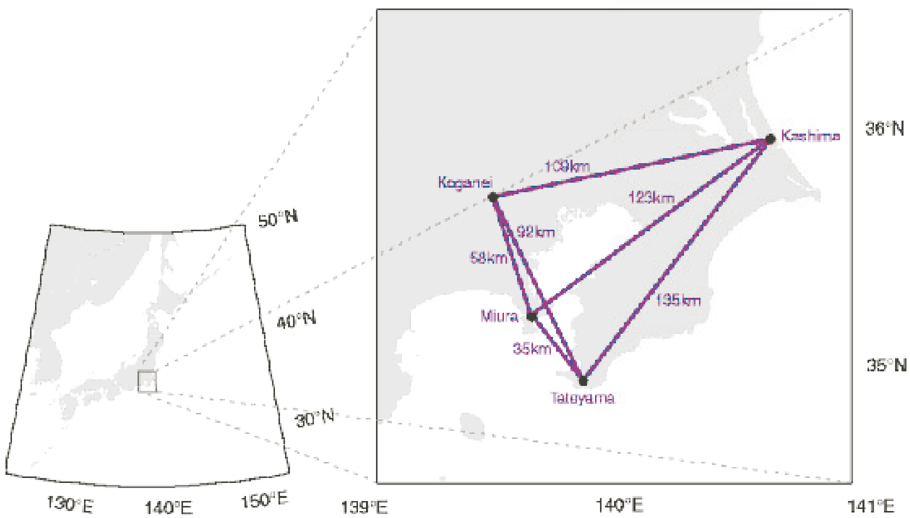

Figure 4. Key Store Project

2.2. Recent experiments of e-VLBI

Several years later, the bandwidth was extremely increased. The Kashima station started the eVLBI collaboration between Kashima and MIT. The Kashima station used the links of the NTT leased line, the Japan-US link of SINET, and Abilene. This experiment started between January 31st and February 1st in 2003. The distance between the stations became much bigger than the Key Stone Project.

3. Actual activities of e-VLBI in Kashima

The first international e-VLBI experiment was sorts of the trial of exchanging the monitoring data. But, the actual experiment becomes the real activities. And it became clear in the network technology are, too. The actual network configuration is shown in the figure. All the links are in the Gigabit level and e-VLBI became ready. But the real infrastructure for eVLBI made clear some issues about the network technology. The issue happened wit the fat pipe link with the long distance between the end users.

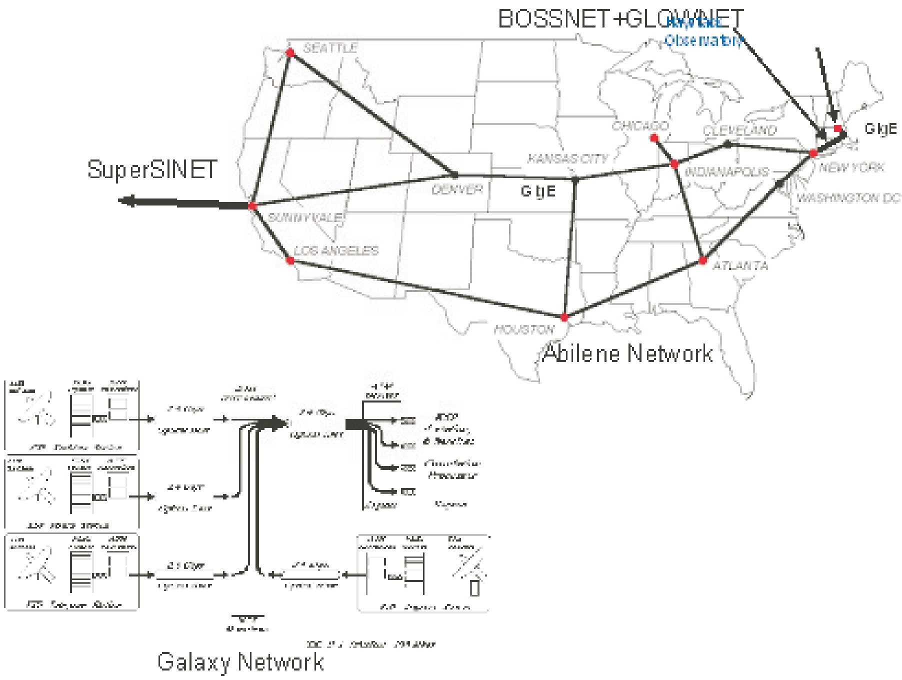

Figure 5. Network Configuration of the current experiment

4. Summary

In Japan, the trial of the eVLBI experiments started when the word "Internet" became popular. But, in those days, the bandwidth was not enough for organizing e-VLBI. As those links were almost congested all day long, they were not the reliable links for exchanging the huge data. And the QoS technology was in the Internet-draft status. But, right now, in Japan, R&E networks provide the next generation Internet service. The e-VLBI over the Internet became in real. Actually, some researchers are trying to develop the application driven path configuration. The e-VLBI is the first candidate of getting such the advanced result.

References

[1] SINET http://www.sinet.ad.jp/english/index.html

[2] JGNII http://www.jgn2.jp/e/index.html

[3] APAN http://apan.net

Performance Measurement on Large Bandwidth-Delay Product Networks

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Abstract

This paper explains performance bottlenecks in high-performance data transfer on large bandwidth-delay product networks and shows a way of tuning a host and identifying path characteristic in order to obtain a reliable experiment result. One of the important factors often neglected is a buffer size on a bottleneck or congestion point. A method of measuring a buffer size is introduced. The impact of bottleneck buffer sizes on performance is also discussed. The technique described in this paper would help applications in identifying a bottleneck and improving the performance along a path.

1. Introduction

It is difficult to control rate of sending data to a long distant place over a packet switched network or Internet while having a feedback from a receiver because the feedback even at light speed takes time to reach the sender. This gets more serious as the bandwidth gets larger because delay of the control would result in a lot of data losses and retransmissions. Experiments have been taken place to evaluate performance of advanced transport protocols on this kind of network with large bandwidth-delay product or BDP. However, sometimes the results from different experiments are inconsistent. It seems difficult to reproduce the similar results in a different place under the same conditions.

This paper explains possible performance bottlenecks and shows a way of removing hidden factors in order to obtain a reliable experiment result under condition of large BDP network. One of the important factors often neglected is a buffer size on a bottleneck. Note that this paper does not discuss about a way of using multiple TCP connections to the total performance that would make the situation more complex and may be harmful in fairness of TCP.

In Section 2, I illustrate why it is so difficult to make use of available bandwidth when conducting high-performance data transfer between distant places. Section 3 explains how to tune a host to get performance. Section 4 shows a way of replaying the bottleneck situation in a testbed and results of the experiment. Section 5 introduces a way of measuring a bottleneck buffer size. Also, it describes a typical problem of network configuration found during the measurement. I conclude in Section 6.

2. Large BDP Network Issue

If network latency is small, TCP can adjust its rate as we expect even with a bottleneck. However, as latency is getting larger, even a minor bottleneck would impact on the performance of TCP between distant places. I explain this scenario here with examples that can bee seen commonly.

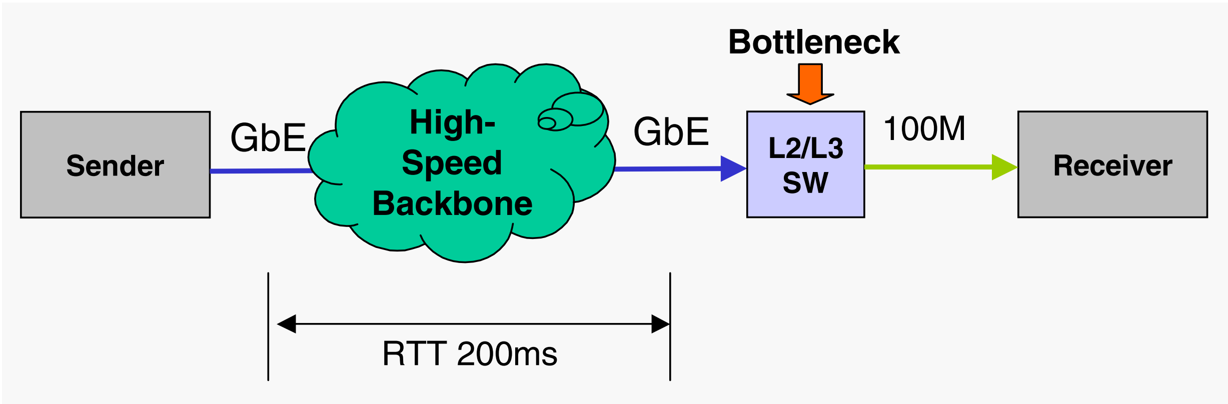

Figure 1. Slower Local Connection on Receiver

Figure 1 shows a case that the local connection on the receiver side is slower than the backbone speed as well as the sender speed. In this case, a bottleneck will be the box that adjusts the speeds. Note that in those cases RTT (Round Trip Time) is assumed at 200 ms (i.e. 100 ms for one-way.)

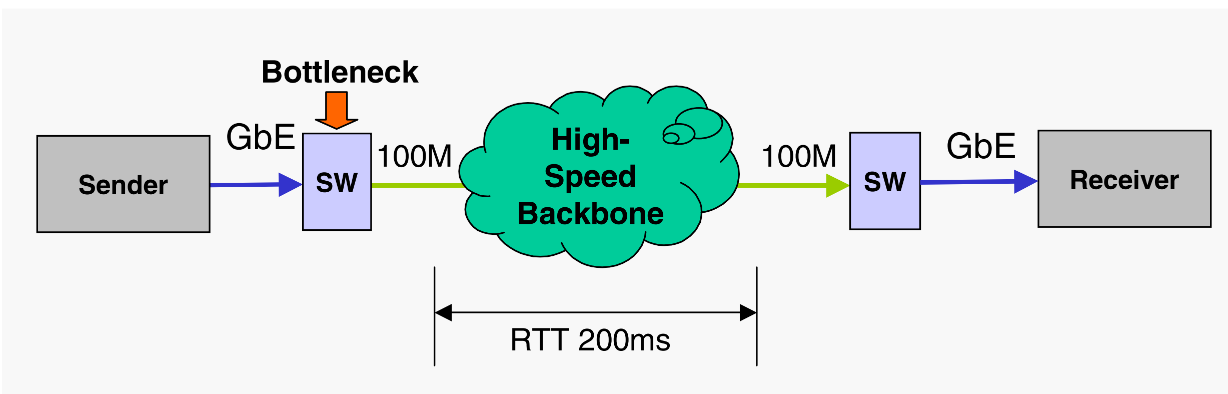

Figure 2. Slower Backbone Connection on Sender

Figure 2 is a similar case but the backbone or an access link to the backbone is slower so that a bottleneck forms on the sender side.

In the both cases, we emulate the situation with conditions of 200 ms RTT and 100 Mbps bottleneck bandwidth between hosts connected at 1 Gbps. In this case, the buffer size at the bottleneck is 100 packets and TCP window size is allocated enough for the BDP. Apparently, if the the sender can only send at 100 Mbps, there is no bottleneck.

Figure 3 shows the results of running regular Reno TCP on Linux 2.4 under the conditions. The TCP throughput in the first 2 minutes is poor with no sender limitation even though there is at least 100 Mbps available all the way. This inefficiency happens because the hosts (more precisely saying, the sender) is tuned to run at 1 Gbps that exceeds the bottleneck bandwidth.

This implies that if we limit and control the rate of sending at a bottleneck bandwidth, it would result in better performance almost at the bottleneck bandwidth. However, it will not go beyond

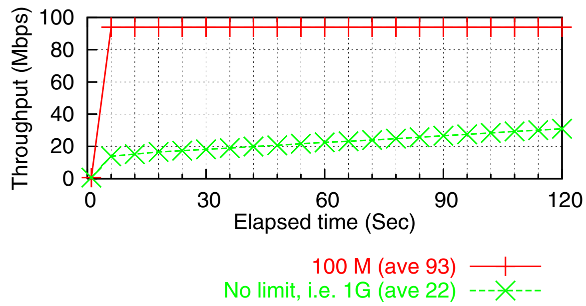

Figure 3. TCP Throughput for the First 2 Minutes

the limit even if more bandwidth becomes available later at the bottleneck. This is a fundamental issue to find an available bandwidth by dynamically controlling the rate of sender. It becomes more difficult under condition of large BDP.

A bottleneck can be formed by many kind of reasons. For example, if there is an ATM connection at 622 Mbps between 1G bps LANs, it is a hard bottleneck like the testbed in this section. A similar situation would happen in case of combination of 1 Gbps and 10 Gbps. It also forms a bottleneck when cross traffic flows at the bottleneck. As long as a packet-switched network or Internet is used, we can not avoid a bottleneck in general.

Note that average TCP throughput from the start and some point varies depending on which point the experiment is stopped. Especially, TCP Reno may take more than 20 minutes to reach its peak rate in case of 800 Mbps bottleneck with a short buffer.

3. Tuning a Host

Before starting an experiment, it is important to remove factors from places that are not relevant. For example, if we are not interested in PCI bus speed, we should use a PCI bus faster than network speed. In this section, I assume that we are interested in only networks under certain conditions and TCP protocols themselves. I introduce a couple tools I have used in the experiments.

3.1. iperf and web100

One of popular tools to measure the performance between two hosts would be *iperf* [2]. The tool generates a traffic in UDP and TCP so it is so-called memory-to-memory transfer without disk access. We are not interested in disk access here. There are a lot of similar tools available but an important feature would be to set a buffer size of socket or transport protocol.

Another helpful tool would be *web100* [1]. It is a kernel enhancement to Linux to export TCP metrics to a user. It also lets us modify a TCP parameter in the kernel. Because TCP behavior changes dynamically, we need to know TCP dynamic behavior in details to identify a problem. This also includes advanced TCP implementations like High-Speed [4], Scalable [5], and BIC [6] as well as other regular TCP enhancements.

3.2. Tuning a Host with UDP

The first step to prepare for a test would be to tune the host with UDP before tackling TCP. Tuning a host with UDP would remove any non-protocol bottleneck on the host.

These days, it is easy to obtain a PC that runs at 1 Gbps. At least, a fast PCI bus like PCI-X mist be equipped because 32bit/33Mhz does not satisfy 1 Gbps speed.

The device driver for NIC can be tuned but it does not help so much. It would be better to find a faster PC rather than tuning the driver. If 10 Gbps is expected, it would be another story and out of scope here.

There are a couple of overhead (headers) at each layer. Ethernet frames include 38 bytes in addition to its payload and IP (version 4) header occupies 20 bytes without IP options, default size of iperf UDP is 1470 bytes, therefore 957 Mbps is the best value iperf can return. This step ends when this value is obtained between two hosts connected back-to-back.

3.3. Tuning a Host with TCP

The second step is to tune a host with TCP. A way of increasing TCP widow sizes are described in many places. In addition to that, Linux TCP treats an event of output buffer full of IP layer interface as a congestion signal, so one of the two options would be required. One is available under web100 kernel. "net.ipv4.WAD_IFQ=1" modifies so that the kernel ignores the full event. The other way is to increase the buffer length ("txqueuelen") of the interface up to BDP.

TCP implementations on Linux as well as BSD keep values of TCP parameters in the last sessions for a destination. So, if we repeat experiments with the same destination in a specific duration, TCP will start with a condition the last time stored. If we use web100 kernel, "net.ipv4.web100_no_metric_save=1" disables this feature in cache. The other way is to flush a cache every time by doing "sysctl -w net.ipv4.route.flush=1".

Like UDP, there is also protocol overhead in TCP so that the best value iperf returns in a regular condition with only TCP timestamps option (10 bytes and 2 bytes padding) would be 941 Mbps. If 802.1Q (VLAN tagging) is used in the network, additional 4 byte overhead is introduced.

4. Evaluating Advanced TCPs in Testbed

This section presents an example of typical network situation with a bottleneck and large BDP. Its equivalent testbed configuration with a network emulator is also introduced. Two advanced TCPs, BIC [6] and FAST [7] are evaluated with different bottleneck buffer sizes.

4.1. Example and Testbed Configuration

Figure 4 illustrates how regular TCP works. This is an example when sending data from Tokyo to Boston. RTT is set to 200 ms. It is assumed that there is a bottleneck of 800 Mbps on the half way at Los Angeles. Both of the sender and the receiver are tuned to work at 1 Gbps.

This example is emulated by a testbed configuration in Figure 5. It is confirmed that the both hosts can send and receive at 1 Gbps in each direction in case of no bandwidth limitation but with 200 ms delay.

If there is an enough buffer on the bottleneck (Los Angeles in this example), it would be fine. However, the buffer size is limited because of hardware limitation like high-speed static RAM

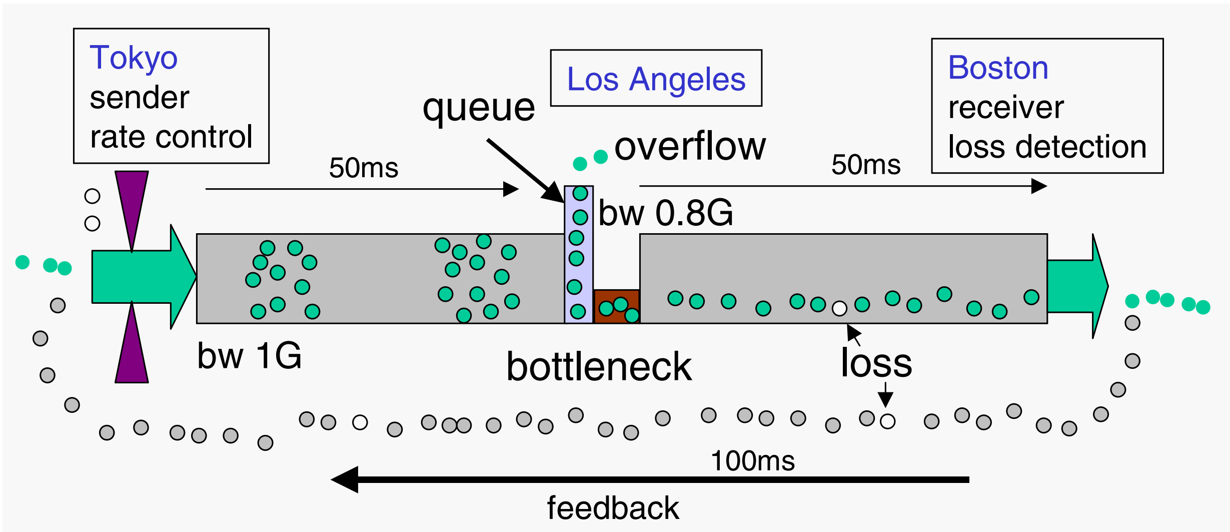

Figure 4. Example of TCP Dynamic Behavior

for the purpose is expensive and less dense than inexpensive but slow Dynamic RAM. In this experiment, buffer sizes of 100 and 1000 packets are chosen to compare because they are typical buffer sizes of a switch and a router, respectively.

4.2. Experiment Results

The result with BIC is shown in Figure 6. Figure 7 shows the result with FAST. Apparently, those advanced TCPs assume larger buffer sizes at a bottleneck. In real networks, depending on its configuration, the bottleneck buffer size varies. This impacts on TCP performance extensively and gives us different results.

5. Identifying a Bottleneck

There are a lot of tools [3] developed to measure capacity and available bandwidth along a path. However, they do not tell us a buffer size at a bottleneck although it is turned out that it impacts on TCP performance from the result in Section 4. In this section, I introduce a way of measuring a buffer size at a bottleneck and explain typical cases of bottlenecks from the results obtained from my initial adoption.

5.1. Measuring a Buffer Size of Bottleneck

The method is straightforward. Just sending a packet train in UDP until it overflows a buffer and detecting losses on the receiving side. Figure 8 illustrates the way.

This measures the time difference between two events of the first packet received and the lost packet detected. Because sending rate is known, the time difference expected in case of no queuing delay can be calculated. Note that this can be measured independent from absolute clock errors on the both ends. The difference of the both values of T, one is measured, the other no delay,

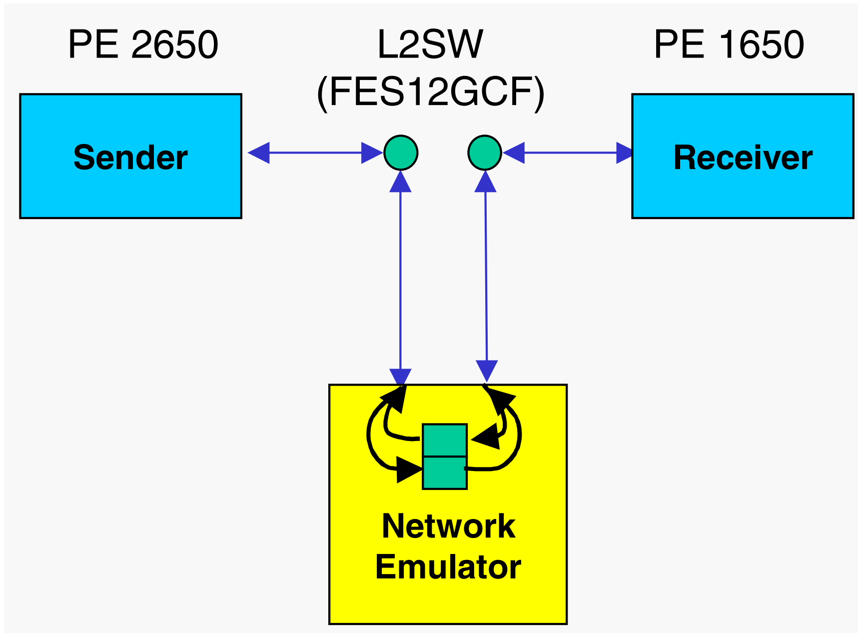

Figure 5. Tesbed Configuration

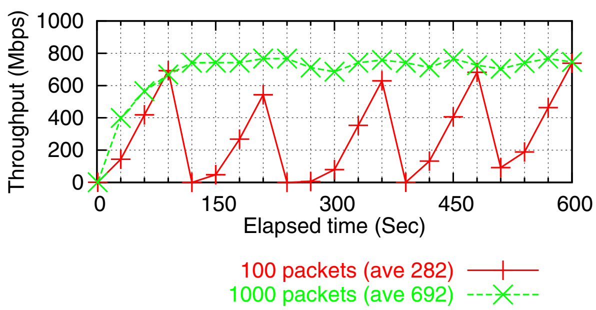

Figure 6. BIC TCP

is a buffering delay. Thus, an estimation of buffer size will be a value of the difference times the capacity.

$Size = Capacity \times (T_{measured} - T_{nodelay})$

The capacity of the bottleneck could be obtained from another measurement tool like pathrate [8]. Apparently, the sender needs to send a packet train at a rate higher than the bottleneck. The first packet traveled is removed from measurement because it may be affected by delays in ARP resolution and cache miss hit of a route look-up on a sender as well as intermediate routers.

I tested a program developed to execute this measurement with the testbed I described in Section 4 and obtained enough accuracy to estimate a bottleneck buffer size. In this paper only a drop-tail FIFO buffer is assumed.

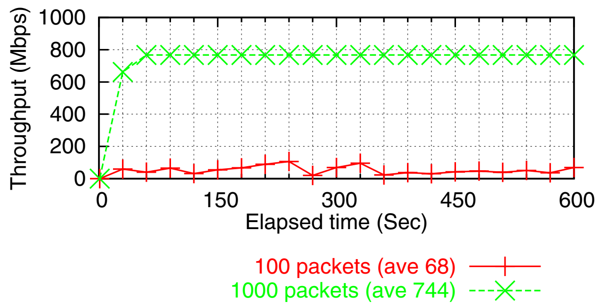

Figure 7. FAST TCP

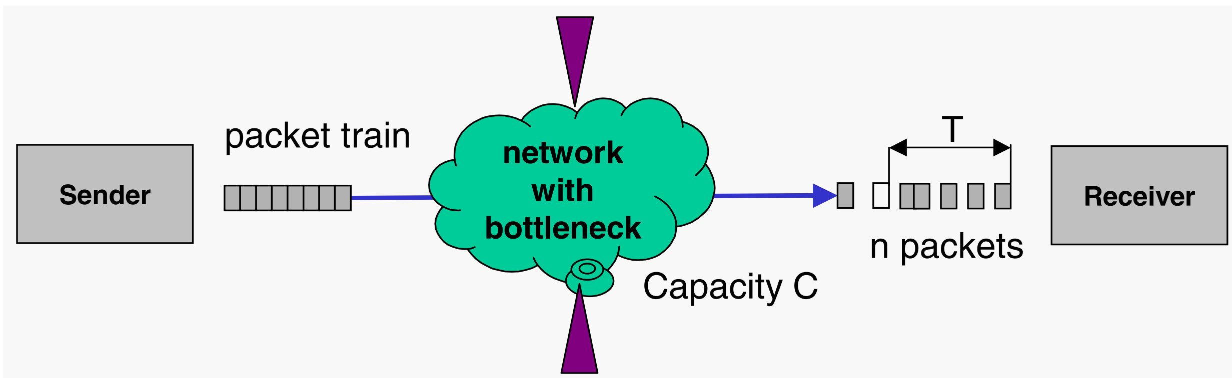

Figure 8. Method of Measuring Buffer Sizes

5.2. Typical Case of Congestion Point

With the tool I developed, I measured a path in a real network and found that a typical bottleneck cases that degrades TCP performance.

In case a) in Figure 9, congestion happens at the switch. Logically, by configuring VLANs between the router and its each peer, it works as if the router has three interfaces like case b). However, The buffer sizes are quite different; switches equips a buffer of about 50-100 packets in most cases, and routers tend to have more than 1000 packets. Therefore, TCP performance is also quite different under the conditions of large BDP between the typical two cases. In summary, using a switch to extend the number of peers would be inexpensive but adding an interface directly on a router would be much better.

6. Conclusion

This paper presents how to tune a host to obtain a reliable result and measure a bottleneck buffer size that impacts on the result. Advanced TCPs exhibit their performance provided an enough size of buffer is available at a bottleneck. A method of measuring buffer sizes is introduced. The impact of bottleneck buffer sizes on performance is also discussed. It should be well considered to place a network device with a short buffer at a congestion point because it would be a major factor of decreasing TCP performance in a fast long distant path. This tuning and measuring

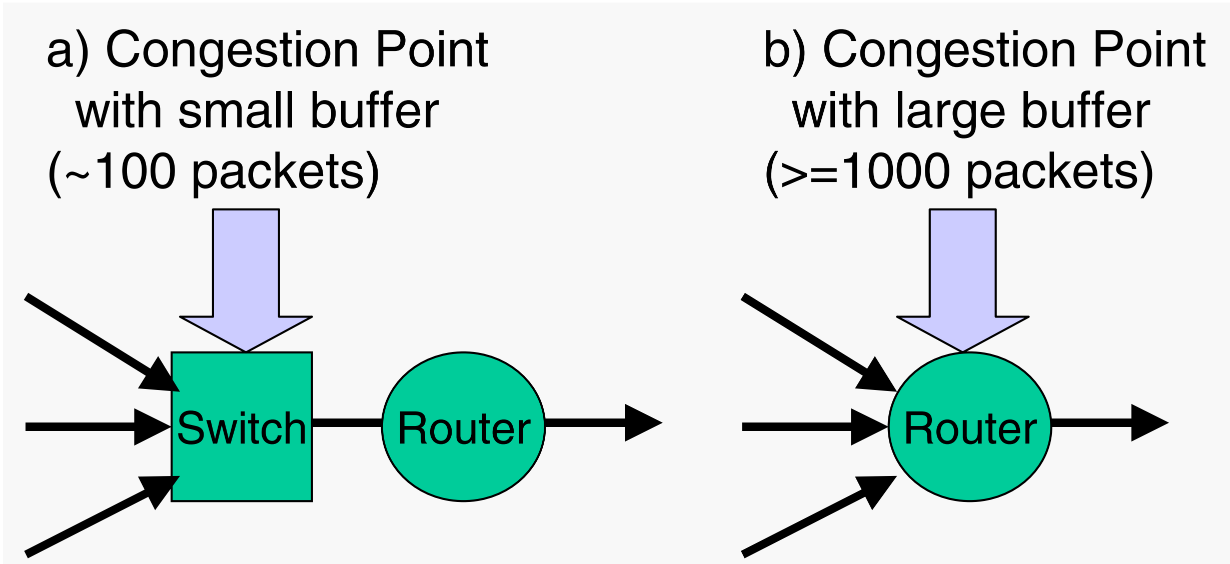

Figure 9. Typical Cases of Congestion Points

technique described in this paper would help applications in identifying a bottleneck and improving performance along a path.

There is a performance measurement platform in cooperation with Internet2 piPEs initiative [9] as well as e-VLBI (Very Long Baseline Interferometry) research groups shown in Figure 10. I am trying to incorporate the way described in this paper into this infrastructure in the near future.

Acknowledgements

I would like to thank Dr. David Lapsley at MIT Haystack, Dr. Yasuhiro Koyama at NICT Kashima, and engineers/researchers at APAN Tokyo XP for their active supports and contribution to this research.

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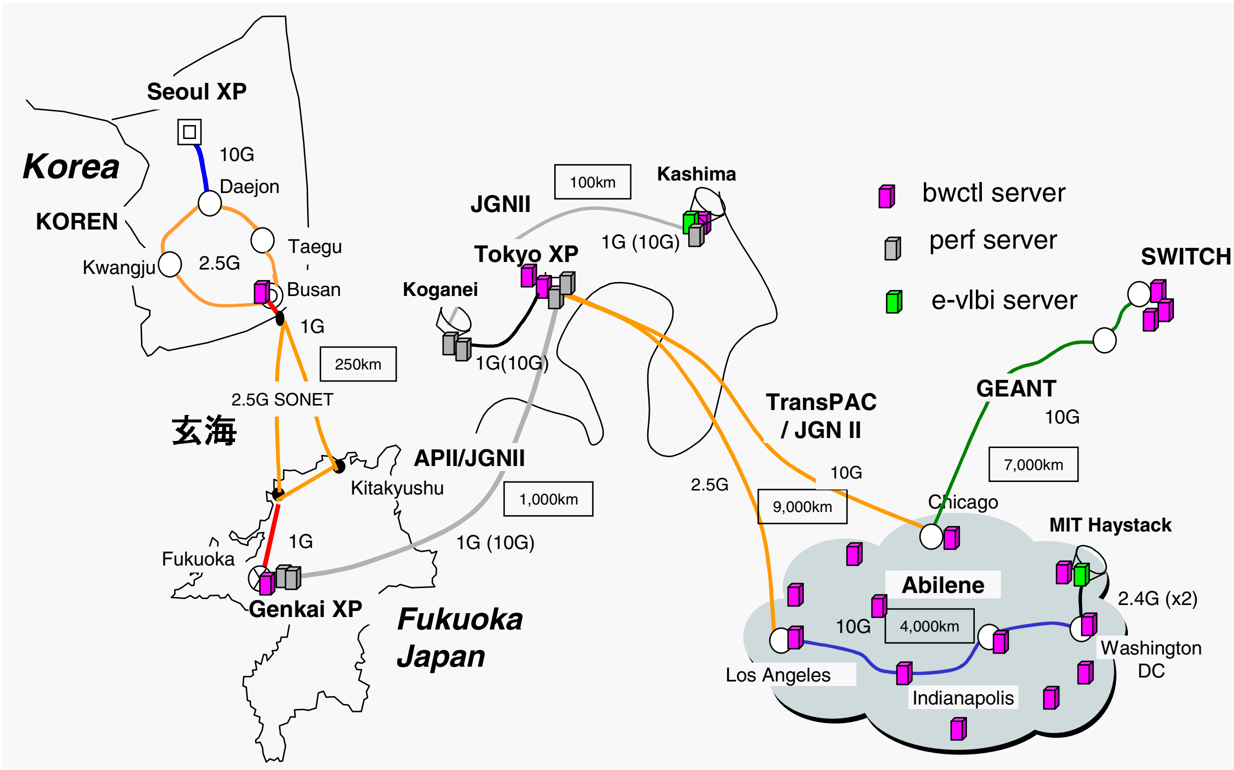

Figure 10. Network Diagram for e-VLBI and Test Servers

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Ongoing e-VLBI Developments with K5 VLBI System

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Abstract

One of the advantages of K5 VLBI system is its high connectivity to the Internet. Because the system is completely included in a commodity PC system, we can utilize the latest commercial PC components in accordance with the development of technology. Network interface of the system had been upgraded to Giga-bit Ethernet and the introduction of 10Gb Ethernet interface is being planned recently. By utilizing the high-speed network connectivity, a network-distributed correlator system had been developed and already used in several VLBI experiments. We report on the architecture of the correlator system in detail. Another advantage of K5 system is its capability to perform several kinds of real-time operations after data acquisition, such as spectrometer, total power meter, oscilloscope, p-cal detector and real-time data transmission. The second half of this paper described the real-time architecture of K5 system and development of digital baseband converter.

1. VLBI correlator with GRID computing technology

We had developed a client/server type distributed VLBI correlator system like SETI@home by using K5 VLBI system [1]. In the system named VLBI@home, received data at VLBI stations are divided into appropriate short-time segments and each segmented data are assigned to a PC. In the case of multi-baseline observations, all the data received at the same moment at different stations are gathered into one PC to minimize data transmission costs. As shown in Figure 1, system consists of following components: control server that controls whole system, database server that stores processing conditions of VLBI data and statistics of each client PC, FTP servers at each VLBI station that transmit observed raw data to clients, and many client PCs with which VLBI data are correlated. When a screensaver-type client software activates, it query the control server about filenames of data to be processed and IP addresses of observed VLBI stations. The client downloads the data from the FTP servers and correlates the data. Resulting data and related information such as download time and correlation time are reported to the database server via the control server. This type of system generally works well when the network speed is faster than the processing speed in the client PCs. At present, K5 software correlator have a capability to process 15 Mbps data in real-time when it runs on a PC equipped with a Pentium4 3GHz. Thus, distributed computing method is useful to increase the speed of correlation processes if the 100Mbps or more high speed network is used. To test the performance, this system was used for the session which intended to estimate UT1-UTC rapidly between Kashima and Westford on June 29, 2004 [2]. After the session, Mark-5 data received at Westford was converted to K5 format, and correlated with VLBI@home. Average processing speed of VLBI@home was 58.6Mbps using 8 consumer PCs in our laboratory. As a result, UT1-UTC estimation was completed 4hours and 30 minutes after the last observation in the session.

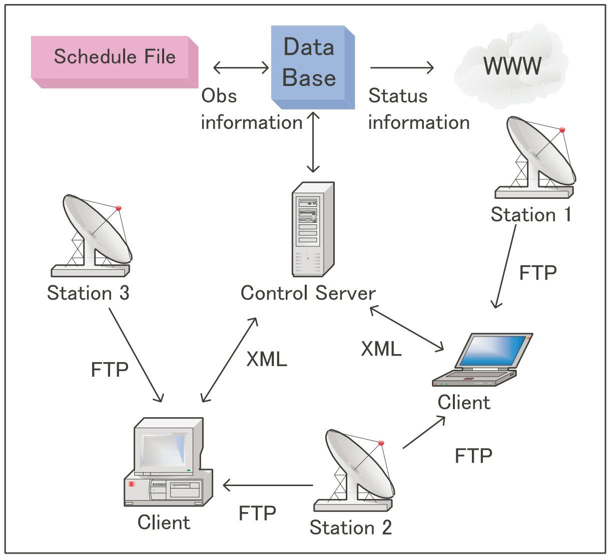

Figure 1. A schematic diagram of the system. Radio signals received at world-wide VLBI stations are transmitted via Internet and correlated in the distributed system.

2. Developments of Software Baseband Converter

A schematic diagram of K5-VSI system is shown in Figure 2. In the system, captured data with a PC is not directly recorded to HDDs, but transferred to PC's shared memory by DMA function. Because of this architecture, multiple software can access the data simultaneously and various kinds of real-time operations are possible by writing software programs. By utilizing this architecture, we had developed software-based baseband converters which down-convert signals from broadband IF (intermediate frequency) to baseband using K5-VSI system [3]. The K5-VSI system consists of gigabit sampler ADS-1000 and a PC equipped with a PC-VSI data capture card and RAID hard disk drives. IF-signals are sampled at the rate of 1Gpbs/2bit or 512Mbps/2bits by ADS-1000 and the sampled data are transferred to the memory in the PC via PC-VSI card.

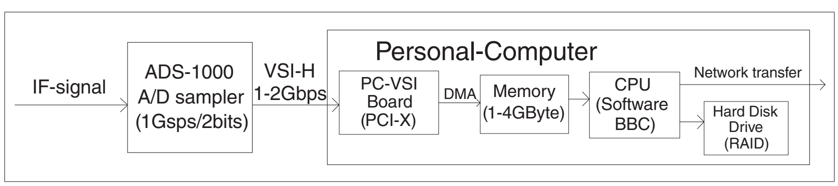

Figure 2. A schematic diagram of the software baseband converter system. Sampled VSI data are written not to HDDs directly but to PC memory so that various kinds of real-time data operations are possible before recording to the HDDs.

When the baseband conversion is not necessary, obtained data are written to the hard disk drives directly. When the BBC mode is on, data in the memory are filtered by band-pass filtering software and resulting data are written to hard disk drives in real-time. The specification of the software BBC is listed in Table 1. The current version of the program has a limitation on selectable baseband frequencies; it must be an integral multiple of baseband bandwidth. A look-up table method is used for the algorithm in order to utilize the high speed memory interface of recent PCs. The data allocation in the look-up table is optimized to ensure the sequential access from CPU to memory. The software is written in assembler language for the purpose of effective use of SSE/SSE2 function, which enables simultaneous four floating operations on x86 machines. It runs about 10-times faster than that written in high-level languages like C language. By using a current PC (Xeon 3GHz, dual CPU), 2 baseband channels can be extracted in real-time from 1Gbps of IF signals.

Table 1. Specifications of the software baseband conveter

Input IF signals	1024 or 512Mbps (1 or 2bit)
Baseband bandwidth	2MH – 64MHz(1,2,4,8bit), USB/LSB selectable
Number of taps	127 – 8191
Baseband frequency	Discrete (Integral multiple of baseband bandwidth)

3. Conclusions

PC-based VLBI system has many advantages for e-VLBI because of its high connectivity to the network and high flexibility. Various kinds of real-time operations are easily realized by PC softwares. A well-known rule of thumb, Gilder's law, indicates the network bandwidth grows at least three times faster than computer power. We expect that distributed computing will become more effective year by year, and play a more important role in near future.

Acknowledgements

The authors would like to appreciate many members of the Haystack Observatory, Joint Institute of VLBI in Europe, Metsähovi Radio Observatory, Shanghai Observatory, Swinburne University of Technology, and NICT for their supports for the e-VLBI developments and observations. Especially, we would like to thank Dr. Steven Tingay and Dr. Craig West of Swinburne University of Technology for providing valuable observation data with which we could evaluate the performance of the software baseband converters.

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Current Status of the K5 Software Correlator

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Abstract

Current status of the performance of K5 software correlator is reported here. The processing speed of K5 software correlator for geodetic VLBI is about 16 Mbps with a Pentium III 1GHz CPU and about 34 Mbps with an AMD Athlon 64 3200+ CPU for calculating 16-lag complex correlation function with detecting phase-calibration-signals. An FX type software correlator for gigabit VLBI system has the throughput of about 500 Msps (mega-sample-per-second) in case of running on an Xserve G5, which corresponds to the throughput of 1 Gbps for 2-bit sampling data.

1. Introduction

The processing speed of software correlator for VLBI data has continued to increase with the improvement of PC performance as well as the use of better algorithm. In the late 1960's, correlation processing was carried out by a software program. A system known as Mark-I used an IBM360/50 computer for correlation processing [*Bare et al.*, 1967]. It took 90 minutes to compute 15-lag correlation function of 200 sec of 720 kbps data, which corresponds to the throughput of about 12.5 kbps for 32-lag correlation. Then Mark-II and Mark-III VLBI systems of which the data rate is much higher than Mark-I were developed. Their data rates are 4 Mbps and 56 Mbps up to 224 Mbps, respectively. Therefore it became impossible to process such a high data-rate data by the software correlator in a realistic processing time. A hardware correlator was hence developed and has been used for a long time. However Kashima VLBI group developed the software correlator named CCC (Cross Correlation in a Computer) run on an HP1000 series minicomputer in 1980's for a fringe test [*Kondo et al.*, 1991]. It took 156 minutes to compute 64-lag correlation function of 4 sec of 4 Mbps data by using a minicomputer HP1000/A900, which corresponds to the throughput of about 3.4 kbps for 32-lag correlation. The CCC was actually used for the fringe test of domestic VLBI, but it was not practical from the reason that not only data processing but also data transmission took time too much (typical transmission speed via telephone line at that time was only 1200 bps). We had to wait for progresses of both computing speed and data transmission speed to put a software correlator in practical use.

Recently a PC shows remarkable progress in the performance to be able to process VLBI data with in a realistic time. Data transmission speed through the Internet also shows a remarkable progress. We then started the development of software correlator again, which can run on a PC. We report the current status of our software correlator focused on its processing speed.

2. K5 Software Correlator

There are two methods to get correlation function. One is to multiply two data stream directly. A correlator based on this method is called an XF type correlator. The correlation function of white noise received in geodetic VLBI observations shows a sharp peak like a delta function, so that we can reduce the number of delay lags, such as down to 32 or less. Furthermore the XF type correlator can be built considerably easily by the combination of simple logic elements. Thus an XF type correlator has been used as a hardware correlator for geodetic VLBI system (e.g., KSP, K3, Mark IV correlators). As for a software correlator the XF type has an advanatage to achieve faster processing speeds by reducing the number of delay lags.

The other method is to use the correlation theorem. Two data streams are first Fourier transformed to the frequency domain, then multiplied each other to obtain cross spectrum. Finally it is inverse Fourier transformed to get a cross-correlation function. A correlator based on this method is called an FX type correlator. This type of correlator can have large number of delay lags easily and is well used for data processing of astronomical application which requires higher spectrum resolution. The VSOP correlator belongs to this type. Both types have been developed as K5 software correlators.

First we developed an XF type software correlator named "cor" to compare the correlation results with those processed by a hardware correlator. The same algorithm used in the KSP hardware correlator is applied to the software correlator to assure geodetic results. Then an FX type software correlator named "fx_cor" was developed for an effective fringe search of geodetic VLBI data. As these software correlators are developed by using a C language, they can run on FreeBSD, Linux, and Windows machines. Since "cor" and "fx_cor" are dedicated to processing multi-channel geodetic-VLBI data, the function of the detection of phase calibration signals injected at a low noise amplifier is implemented in these softwares.

3. Current performance status

Figure 1 represents the results of bench mark test evaluating the processing speed of the "cor" and "fx_cor". The throughput of processing 4ch 1-bit-8MHz sampling data are plotted as a function of the number of delay lags for XF ("cor") and FX ("fx_cor") software correlators. A PC equipped with a Pentium-III 1GHz CPU is used for the bench mark test. The processing speed of FX type is not so influenced by the increase in delay lags, but that of XF type decreases in proportion to the number of lags. When the number of lags is less than 512, the processing speed of the "cor" is faster than the "fx_cor".

We also tested the processing speed of K5 cor for various kinds of CPUs and clock frequencies, such as Pentium III, Pentium 4, AMD, Celeron, etc. Throughputs are shown in Figure 2, where data used are 4ch 1bit-8MHz sampling (=32 Mbps) data, and 32-lag complex correlation function is computed. At present time, the throughput of about 17 Mbps is achieved for an AMD Athlon64 3200+ CPU in case of computing 32-lag correlation, which corresponds to 34 Mbps for 16-lag correlation considering from the relation between lag number and throughput shown in Figure 1. The throughput of Pentium4 2.5GHz CPU is about 12 Mbps for 32-lag correlation and 24 Mbps for 16-lag correlation. It is clear from the figure that the processing speed increases with the clock frequency, so that we can expect faster throughput in the future if the progress in CPU performance continues.

We have also developed an FX-type software correlator (K5-FX), which is specialized for processing speed to process gigabit VLBI system data, mostly for an astronomical use [*Kimura & Nakajima,* 2002; *Kimura et al.,* 2003]. In order to maximize the performance of CPU, various kinds of optimizations, such as an effective use of multi-processors and utilization of SIMD (Single

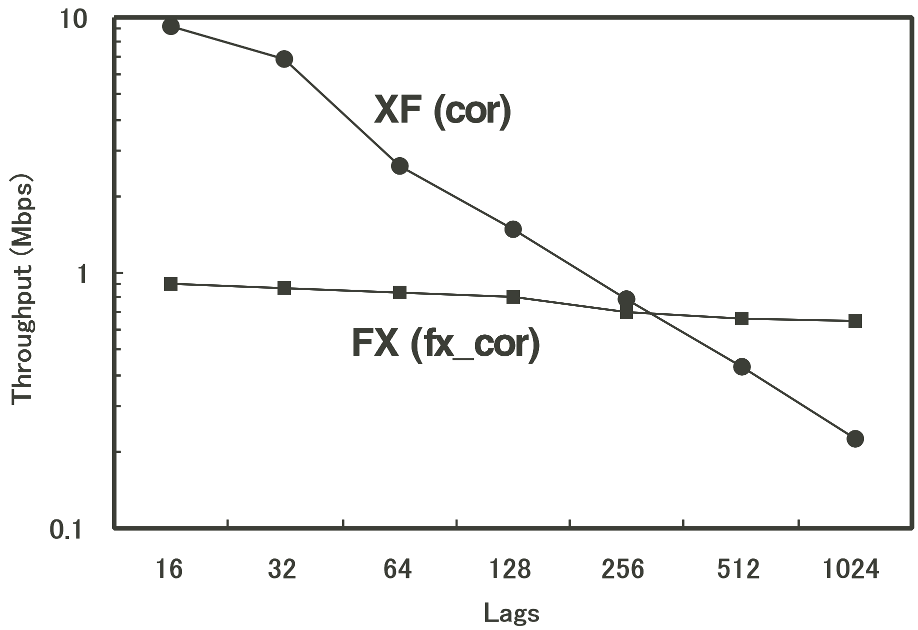

Figure 1. Current performance of K5 software correlator. Throughputs are plotted as a function of the number of delay lags for XF ("cor") and FX ("fx_cor") software correlators. A CPU used for the test is Pentium-III 1GHz.

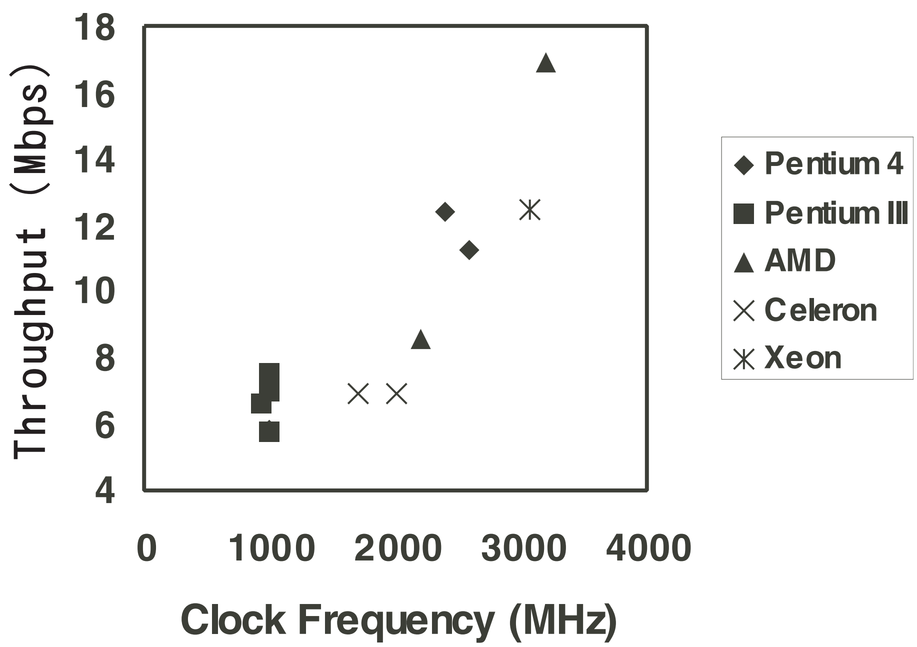

Figure 2. Comparison of the processing speed for various kinds of CPUs and clock frequencies. Throughputs for computing 32-lag correlation function is plotted.

Instruction Multiple Data) technology for parallel processing, are applied into the software. An assembler language program is also used partially to improve the performance. Figure 3 shows results of benchmark test of the K5-FX software correlator using an Xserve G5 equipped with dual 2GHz G5 processors. Throughput is measured for different number of FFT points. It reaches up to about 500 Msps (sample per second) at 1024 FFT points, which corresponds to the processing speed of 1 Gbps for 2 bit sampling data. The size of cash memory of CPU affected the performance at large number of lags, results in the performance loss.

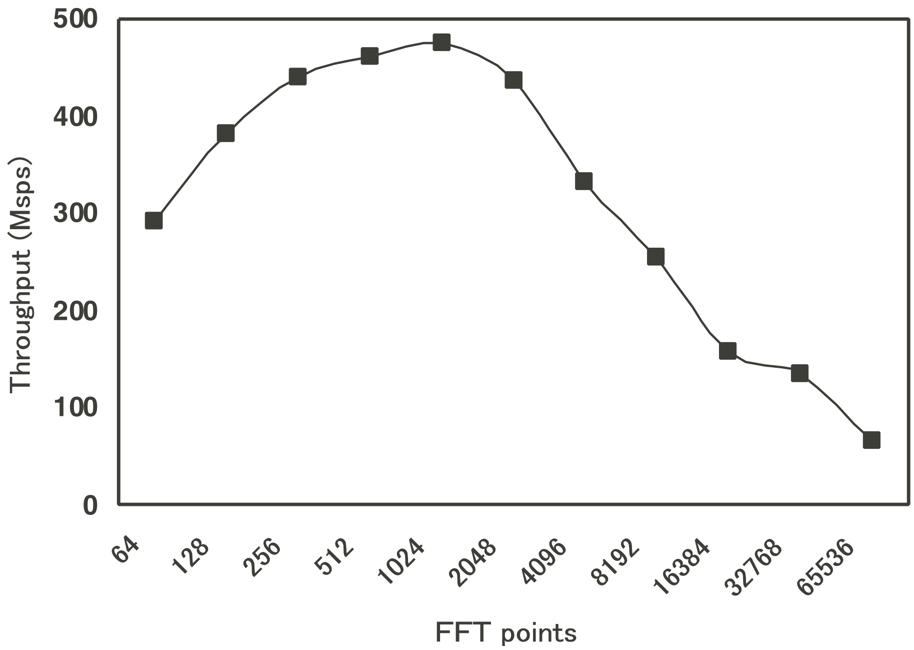

Figure 3. Benchmark test results of K5-FX software correlator using an Xserve G5 equipped with dual 2GHz G5 processors. Throughputs is measured for different numbers of FFT points.

4. Conclusion

The K5 software correlators, "cor" and "fx_cor", were developed for geodetic VLBI data processing. At present time processing speed of "cor" is about 17 Mbps for computing 32-lag correlation using an AMD Athlon64 3200+ CPU, which corresponds to 34 Mbps for 16-lag correlation. We have been developing a distributed processing system that can apply to both "cor" and "fx_cor" to increase total processing speed [*Takeuchi et al.,* 2004]. K5-FX is the software correlator developed for a gigabit VLBI data processing. It shows quite high performance capable to process 1 Gbps data in real-time by use of only one PC.

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Rapid turn around UT1 estimation with e-VLBI

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Abstract

On June 29, 2004, one hour e-VLBI session between Westford and Kashima stations was performed to obtain UT1 estimation as soon as possible. The observed data were transferred and processed promptly after the observing session, rapid turn around UT1 estimation was demonstrated as short as about 4.5 hours after the session. Following the success, extra intensive session series between Tsukuba and Wettzell stations on every Sundays was initiated to fill the remaining day of the week for the intensive sessions. By establishing the Sunday intensive sessions, UT1 estimation from VLBI observations have become possible everyday. We will report the results of the demonstration session and discuss about extending the e-VLBI into the other IVS sessions.

1. Introduction

In 2003, we reported about the results of a test e-VLBI session performed on June 27, 2003 with the baseline between Kashima 34m and Westford 18m stations[1]. The observations were performed for about two hours at the total effective data rate of 56Mbps, and the data were processed using both Mark-4 correlator at Haystack Observatory and K5 software correlator at Kashima. By using the K5 correlator outputs, UT1-UTC was estimated at about 21 hours 20 minutes after the last observation completed [2]. Following this successful demonstration of e-VLBI technique to determine UT1-UTC value so rapidly, Observing Program Committee of the IVS started to discuss the possibility to introduce the e-VLBI technique to the routine international VLBI sessions coordinated by IVS. The capability of the rapid UT1-UTC estimation is considered to be best utilised by the single baseline intensive sessions and it was recommended to try to establish routine e-VLBI session series every Sunday. Until recently, the intensive sessions were performed by using a baseline between Kokee Park and Wettzell stations on weekdays (from Monday through Friday), and by using a baseline between Wettzell and Tsukuba stations on Saturdays. By filling the vacant Sundays by using the e-VLBI intensive sessions, daily monitoring of UT1-UTC can be realized and it was considered to be the best way to introduce the e-VLBI in the regular session. If these e-VLBI sessions are considered to be smooth and reliable, efforts will follow to make the e-VLBI becomes possible for the existing intensive sessions to improve the latency of the UT1-UTC estimation. In this scope, we have performed two e-VLBI sessions again by the baseline between Westford and Kashima 34m stations to prepare the necessary softwares to establish the routine e-VLBI intensive sessions. In this report, we will describe the recent developments to improve the software correlations and the network connectivities and will discuss about the results obtained by the test sessions.

2. Developments of the K5 Software Correlator

After the test e-VLBI sessions in 2003, the software correlation programs for the K5 software correlator have been improved for their processing speed [3]. In addition, efforts have been made to realize distributed processing by using multiple CPUs. One of the efforts is to utilise unused CPU powers of the conventional PC systems by developing a screen saver program to download the data files from a server and perform the software correlation [4]. The mechanism, which we are calling as VLBI@home, is consisted by a screen saver program and a server system program. The server system program processes the requests from the clients systems running the screen saver program. Currently, the screen saver program has been developed on the Microsoft Windows operating platforms. Any PCs connected to the Internet can be used as the clients. Once the screen saver program is installed, the program begins to communicate with the server program over the Internet and begin to download the data files and then perform the correlation processing. Once the processing completes, the results will be reported to the server program and then the client system begins to process the next data set. If the user of the PC system starts to use the CPU for the other purposes, the screen saver program promptly terminates the processing but the processing can be resumed later when the CPU is not used for a certain time specified by the screen saver configuration.

In addition to the VLBI@home programs, a simple server and client mechanism shown in Figure 1 has also been developed by using simple shell scripts and Fortran programs. On the server system, a master control file 'master.txt' is maintained and the file holds all the information necessary to control the distributed processing. By reading the master control file, the server system can assign a set of data files with which the client systems can process. Each client system obtains the data files and necessary information from the server system and starts to process the data. When the processing is completed at the client system, the client system places the results to a specific place and then requests the server system for the next data files. By using this simple mechanism, all the data files can be processed effectively using available computing resources of the client PC systems. Although the performance of each PC system may differ, each client PC systems can process the data files according to the available performance. Status monitoring capability is also under developments as shown in Figure 2. Any WWW browsers can display current status how the distributed processing is on going. In this server and client mechanism, data files are accessed by using the Network File Server (NFS) protocol. The disks where the data files are located are mutually mounted by multiple Linux and Free BSD unix servers by using amd (Auto Mount Daemon) or autofs programs. The processed results are written onto a single disk which is also mounted by the NFS from the clients. To avoid multiple access to the master control file, the server system creates a empty 'lock' file when it starts to process the master control file and access to the file is prohibited as far as the lock file is existing. After the modifications to the master control file, the lock file is removed and the other processes is allowed to process the file. In this way, the client systems can process the correlation processing independently without the tight control from the server system. This mechanism is very simple but it works very well even when the performance of the client systems are not uniform. The master control file contains information when the job is started by which client system and can reset the status when the results are not reported within a specified timeout time. By doing this, the client program can start or stop at any time.

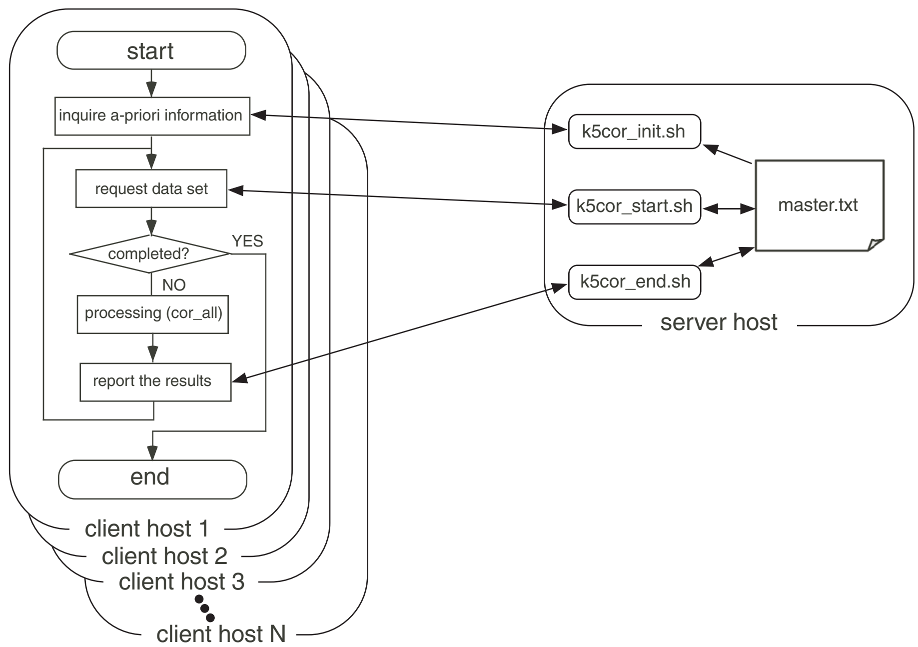

Figure 1. A schematic diagram of the server and client mechanism developed for the distributed cross correlation processing.

3. Improvements of the Network Connectivities

After the test e-VLBI sessions in 2003, the GALAXY network connection to the Kashima Space Research Center was terminated. The GALAXY network is a high speed dedicated research network for e-VLBI coordinated by the collaborations among NICT, NTT Laboratories, National Astronomical Observatory, and Japan Aerospace Exploration Agency [5]. Before the termination of the connection, Kashima and Musashino R&D Center of the NTT Laboratories used to be connected by the OC-48 ATM network and GbE Ethernet was supported over the ATM network. The TCP/IP connection was then routed to the Abilene network in the United States via the GEMnet network coordinated by the NTT Laboratories. The connection was used for the two test e-VLBI sessions in 2003.

Since the GALAXY connection to Kashima was terminated in 2003, the institutional LAN connection inside NICT between Kashima and Koganei headquarters had been only available for the e-VLBI data transfer from the stations at Kashima. The connection between Kashima and Koganei has the maximum bandwidth of 100Mbps and the network is shared by many traffic form the various purposes among many projects of the NICT. By using this connection, we started to record all of the observation data for the IVS geodetic VLBI sessions at Kashima 34m station with the K5 system since October 2003, and to transfer K5 data files to the server at Haystack Observatory or in Washington D. C. and then used for correlation processing after converting the data file format to the Mark-5 system [5]. The typical data transfer rate was about 30Mbps after tuning various network parameters and using multiple TCP/IP connections by using bbftp program.

On the other hand, an independent high speed research network in Japan based on ATM used

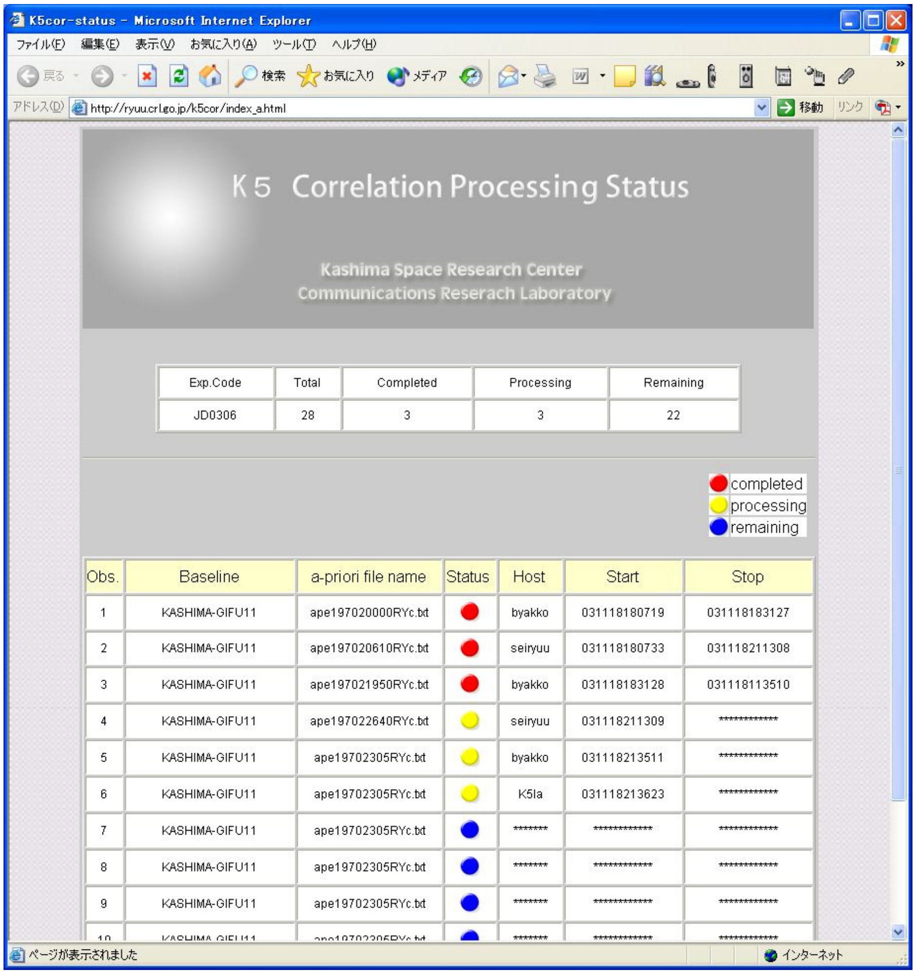

Figure 2. A WWW browser screen for monitoring distributed processing status under developments.

to be operated by Telecommunications Advancement Organisation (TAO) to support advanced research and developments for the communications technology. The network was called Japan Gigabit Network (JGN) and it supported many research projects. In April 2004, the TAO and Communications Research Laboratory were merged and the new institute was established as NICT. At the same time, the JGN network was upgraded and the new research test-bed network Japan Gigabit Network II (JGNII) was established based on the TCP/IP network. As shown in the Figure 3, Kashima and Koganei was connected by the OC-192 (10Gbps) connection and a GbE TCP/IP connection was established between these sites. The TCP/IP network is then routed to the Abilene network in the United States via JGNII/TransPAC network. As shown in Figure 4, the connection between JGNII and the Abilene was upgrade to two lines of OC-48 connections in August 2004.

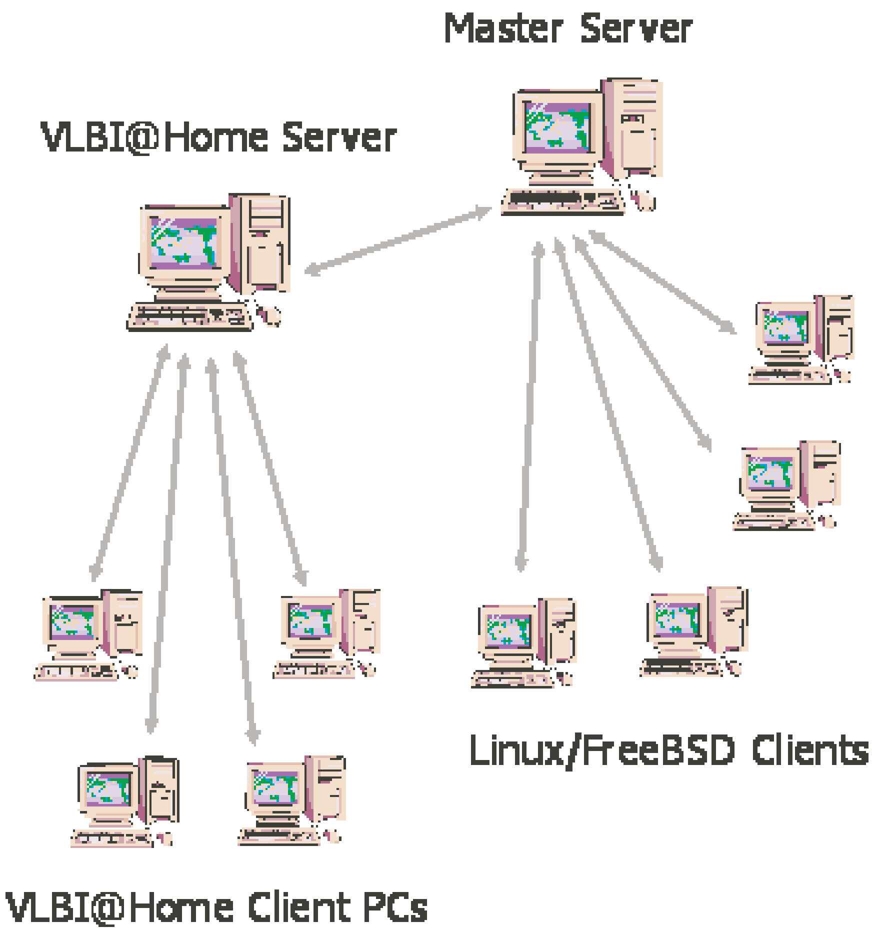

Figure 3. Configuration of the high speed network in Japan.

4. Experiments

As explained in the Introduction, two test e-VLBI session were performed in June 2004. The first session was performed for about two hours from 19:00 UT on June 22. The purpose of the first session is to use it as a rehearsal. By processing the observed data in the first session, it was estimated that one hour of observations would be enough to estimate UT1-UTC with the uncertainty of 20 microsec. Therefore, the second session was performed for about one hour. After the observations, the data recorded at Westford station with the Mark-5 system were extracted and transferred to Kashima through Abilene/TransPAC/JGNII networks. 13.5 GBytes of data were transferred in about 1 hour and 15 minutes and the average data transfer rate was 24 Mbps. The transferred data were then converted to the K5 file format. During the one hour session, 18 scans were recorded in total. 13 scans were assigned to the NFS based distributed software correlation using 12 CPUs running on Linux and FreeBSD. The remaining 5 scans were assigned to VLBI@home and 9 CPUs were used. As soon as the data format conversion completed, the software correlation was started. At this point, the network connection at Kashima became unstable and

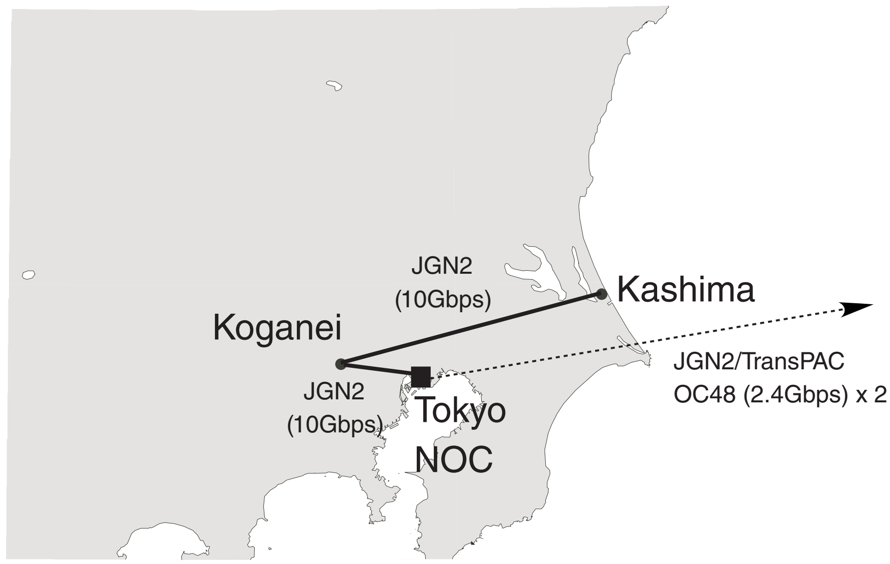

Figure 4. Configuration of the high speed network in the United States.

the data access became very slow. To solve this problem, the servers were rebooted a few times and these operations caused the unexpected delay of the processing. As the results, it took about 2 hours and 38 minutes. Immediately after all the correlation processing completed, database files were generated and the data analysis was performed by using CALC and SOLVE softwares developed by the Goddard Space Flight Center of NASA. The data analysis was completed at about 4 hours and 30 minutes after the last observation in the session completed. Table 1 shows the time sequence from the observations. After the demonstration, the distributed software correlations were repeatedly performed with the same condition, but the network problem which caused the delay did not occur again. If the problem did not occur, the software correlation processing would have been completed within 30 minutes. Therefore, it will be possible to estimate UT1-UTC from the similar test session within 3 hours after the observing session. During the test e-VLBI sessions in June 2004, many procedures were still performed manually while many procedures have been automated. But the situation will improve as the software developments advance.

Table 1. Time sequence from observations through the data analysis of the e-VLBI session on June 29, 2004

Events	Time in UT (Date)
Observing session started	19:00 (June 29)
Observing session finished	20:00
File transfer started	20:13
File transfer completed	21:28
Correlation processing completed	00:16 (June 30)
Data analysis completed	00:30

For both of the two test e-VLBI sessions, effective data rate was 56Mbps. Frequency bandwidth for each channel was 2MHz. For X-band, 8 channels were used while the remaining 6 channels were used for S-band. In the data analysis, atmospheric delay and clock offset were estimated as well as the value of UT1-UTC. The formal uncertainty of the UT1-UTC estimation was 22.0 microsec.

5. Routine e-VLBI Intensive Session

Since the demonstration of rapid turn around UT1 estimation was successful, a routine intensive VLBI session was initiated by using Tsukuba and Wettsell stations on August 29, 2004. For the time being, only the last session every month will be performed as an e-VLBI session whereas the other sessions will be performed by using K4 system and the observation tape cassette will be correlated at Tsukuba by using K4 correlator system. Intensive e-VLBI session will be performed by using K5 system at Tsukuba and Mark-5 system at Wettzell. The Mark-5 data recorded at Wettzell are extracted and transfered to Tsukuba by using usual FTP program. The transferred files are then converted to the K5 data file format and correlated with the K5 data recorded at Tsukuba by using K5 software correlator program. Tsukuba station has been connected to NTT Musashino R&D Center with two 2.4Gbps ATM links as part of the GALAXY network. A GbE TCP/IP data transfer is possible by using a set of TCP/IP interfaces at Tsukuba and Musashino on one of the links. At present, TCP/IP connection is only possible when the other purposes do not use the ATM connection, but we are planing to improve the situation by using an ATM switch at Tsukuba station.

As of October 2004, two e-VLBI sessions were performed. Although the data processing of the first session was not smooth, the procedures and programs were improved and the second session was processed smoothly and the UT1 was estimated within 3 days from the session. By accumulating experiences and further improving the procedures, we are planning to increase the e-VLBI sessions in the Sunday intensive sessions and then Saturday intensive sessions in near future. To realize the smooth transition of all intensive sessions into e-VLBI, it will be necessary to automate the procedure of data transfer and data processing as much as possible.

6. Conclusions and Future Plans

With the test e-VLBI session in June 2004, the capability of rapid turn-around estimation of UT1-UTC from one baseline e-VLBI session was successfully demonstrated. Following the success, e-VLBI session is being gradually introduced into routine VLBI sessions. The network connection from the Westford station of the Haystack Observatory to the Abilene network was upgraded to OC-48 (2.4Gbps). The US-Japan connection of the JGNII/TransPAC network was also upgraded in August 2004 and Chicago and Tokyo is connected with an OC-192 (10Gbps) line. It seems promising that the network connectivity at many VLBI station sites will be improved in near future and the number of stations with e-VLBI capability will rapidly increase. To make the e-VLBI more robust and effective, it is important to investigate the various bottle necks. One of the current bottle necks is the necessity of file format conversion. This problem will be solved if we use uniform data transmission protocol. To realize the standard protocol for e-VLBI, VSI-E (VSI = VLBI Standard Interface) protocol is proposed and is under discussion. The heavy use of NFS has a potential problem to become a bottle neck when multiple baselines have to be processed by distributed software correlation. There are at least two efforts to improve the performance of the NFS. One is the GRIDfarm software based on the developments of the GRID computing. Another effort is called SRFS (Shared Rapid File System) which realises robust and fast file sharing over the network. It seems worth investigating the effect of using these available tools. By eliminating possible bottle necks, we expect we can introduce e-VLBI operations on the routine IVS VLBI sessions in an effective and smooth manner.

Acknowledgements

The authors would like to appreciate many members of the Haystack Observatory and NICT for supporting the e-VLBI developments and observations. Research partners at the NTT Communications Corporation, KDDI R&D Laboratories, NTT Laboratories, JGNII, and Internet2 have made the e-VLBI session possible together. e-VLBI research and developments in Japan have been promoted by a close collaboration of NICT, Geographical Survey Institute, NTT Laboratories, National Astronomical Observatory, Japan Aerospace Exploration Agency, Gifu University and Yamaguchi University.

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Throughput Test of Satellite Data Transmission for Space Geodesy using the TCP/IP link in the South Pacific

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Abstract

We performed the data transmission tests from Fiji to Japan using the TCP/IP satellite communication link in order to evaluate the data throughput rate for transmitting the VLBI and GPS data sets. The average throughput using the state-of-art satellite router is up to 1.44Mbps which value is about 94% of the nominal maximum throughput.

1. Introduction

The monitoring of the earth orientation in real-time or quasi-real-time with high precision is very significant for precise orbit determination of global navigation satellite systems such as GPS and GLONASS. In addition, such earth orientation information is needed for the real-time positioning of interplanetary spacecraft. In order to realize such monitoring, new VLBI technology is under development. The new VLBI technology includes the "K5 VLBI system", a small dish antenna, and the high speed and wideband data transfer equipment. The K5 system includes the multiple PC-based VLBI system and the original software packages including data sampling and acquisition, real-time IP data transmission, and correlation analysis.

Though full-time observations at globally distributed VLBI stations are desirable for the real-time monitoring of the earth orientation, Pacific and southern hemisphere coverage is not sufficient. If we are able to use a high speed TCP/IP data link using an optical fiber network or wideband satellite communication at the South Pacific Islands, our new VLBI system will be used to fill a gap in the VLBI observation network. In addition, the monitoring of the plate motions and sea level changes using GPS measurements in the South Pacific supports studies of natural hazards and climate change.

Unfortunately, since there are no VLBI stations in the South Pacific Islands, the position coordinates of GPS stations are not tied to the global reference system with sufficient precision. The local tie between the VLBI station and the local GPS network will improve the precision.

Thus, we started to perform the VLBI and GPS data transfer experiment using the satellite TCP/IP link. In this short report, we describe our preliminary result to examine the data throughput rate of the link.

2. TCP/IP Data Transfer using Satellite Communication Link

The satellite communication system over the West Pacific is available to evaluate the feasibility of GPS and VLBI data transmission. There is one satellite station in the University of South Pacific (USP), SUVA, Fiji. Though the band width of 1536Kbps is not enough to transmit the huge data sets such as Gigabit VLBI data, we can actually evaluate the R&D results to send the space geodetic data from Fiji to Japan.

Our first experiment was successfully carried out during the period of February 9-14, 2004. The schematic image of our experiment and the network configuration are shown in Figure 1 and Figure 2, respectively.

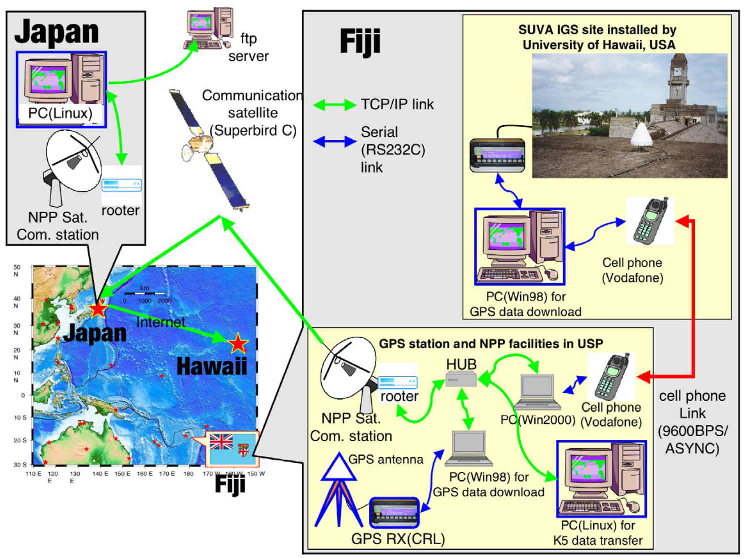

Figure 1. **Schematic image of the data transmission experiment.**

We installed a GPS station, a pre-installed Linux server including the test VLBI data, and a state-of-the-art satellite router in the USP. The formula (1) commonly used to determine maximum session throughput with a given RTT is:

$$Throughput[bit/sec] = 8 \times RWIN[KB]/RTT[sec] \quad (1)$$

Throughput is displayed in bits per second. RWIN equals the size of the TCP/IP stack in bytes (ex. default is 8192 in Windows98). RTT is the round trip time in seconds. For example, if the RTT across a geostationary satellite link and back is 540 millisecond, the maximum throughput is limited to about 119Kbps.

The router can improve the maximum throughput of a TCP connection to avoid the time delay due to the RTT using new technology known as “spoofing”. This technique gives a quick response back to the sender on the local end as if the link had no propagation delay. Spoofing also includes techniques to request resends for bad packets, thus ensuring an error free transmission. With spoofing, an individual user IP session can achieve a throughput that is nearly equal to the overall link speed, without regard for propagation delay.

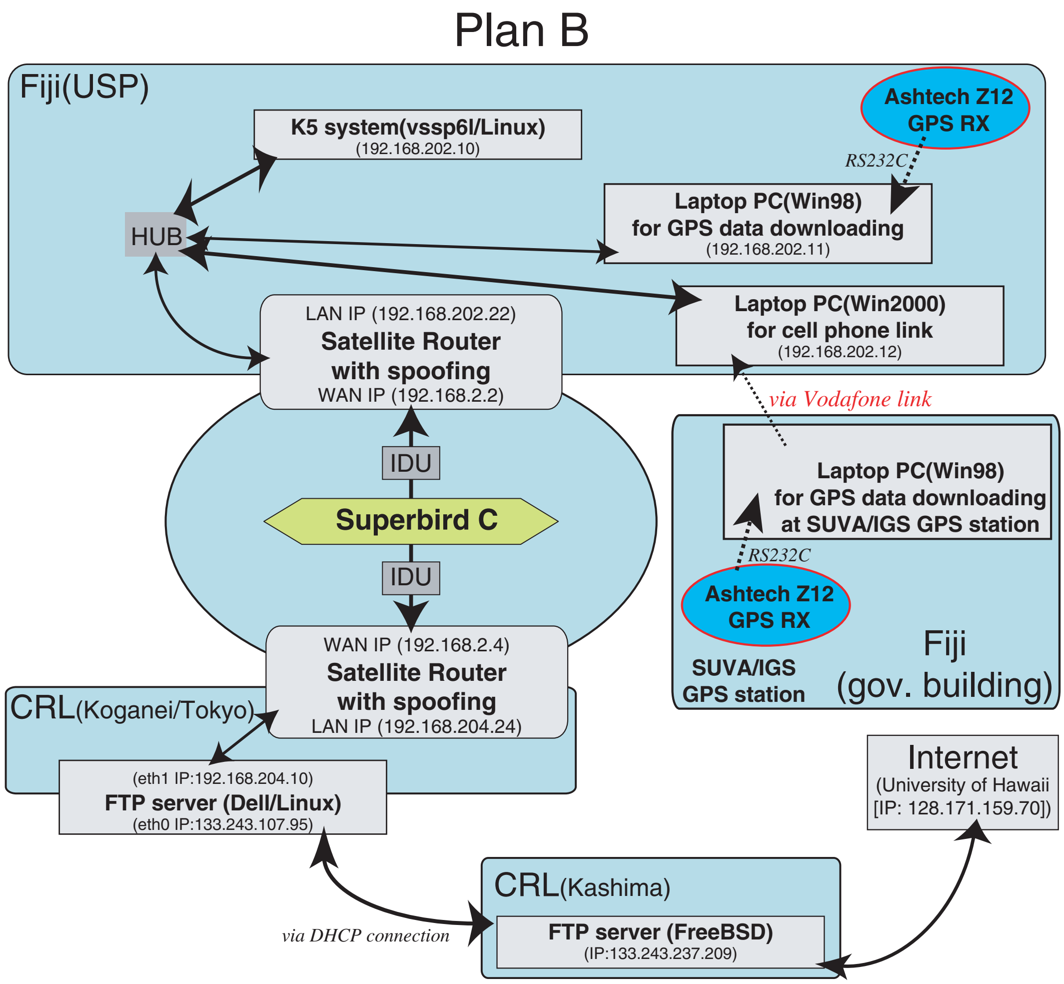

Figure 2. **Network configuration of the experiment.**

3. Results

First, we measured the link speed of the TCP/IP satellite connection using a throughput tester "iperf". In this test the RTT was 536 millisecond. The result of data throughput tests is shown in Figure 3.

We carried out the throughput test for each RWIN size(8, 16, 32, 64,and 128KB). In the case of "spoofing off"(left of Figure 3), it is clear that the throughput rate depends on the RWIN size. On the other hand, in the case of "spoofing on"(right of Figure 3), the throughput rate is stable and is close to the nominal maximum value of 1.536Mbps.

Next, the GPS and VLBI data sets in the USP server were transmitted via FTP from Fiji to Japan. In this experiment, about 200MB K5 test data and about 980KB GPS RINEX data were transmitted. The average throughput was more than approximately 1.44Mbps which is up to about 94% of the nominal maximum throughput. The GPS data sets were also transmitted via FTP to the external server at Kashima Space Research Center and the University of Hawaii. These results indicates that the satellite router is significantly effective to send the data using the

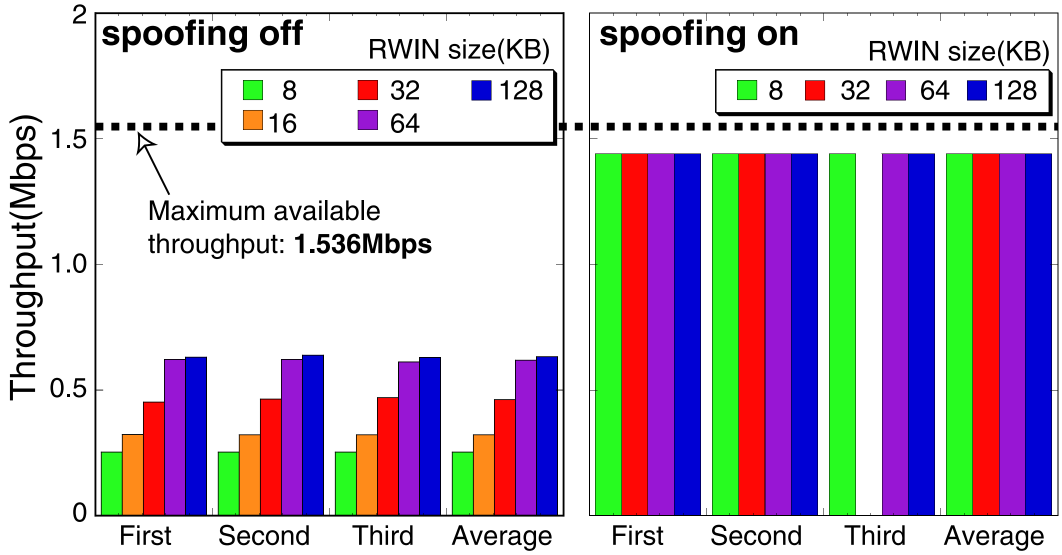

Figure 3. **Data throughput performance of the new satellite router measured by "iperf" throughput tester (Left:spoofing off, right:spoofing on).**

TCP/IP satellite link without latency.

In addition, we also tried to take the IGS/GPS data at the government building in SUVA using dialup access from the PC in the USP satellite station during the experiment. However, this data link was not successful due to the software problem.

4. Concluding Remarks

We performed the data transmission tests from Fiji to Japan using the TCP/IP satellite communication link. The both results of iperf test and the ftp transmission test for VLBI and GPS data sets demonstrate that the average throughput is about 1.44Mbps, which value is up to about 94% of the nominal maximum throughput, using the new satellite router.

Astrometry Observation of Spacecraft with Phase delay

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Abstract

We are investigating technique of VLBI application for spacecraft navigation. Group delay measurement of radio signal from spacecraft has been used for spacecraft navigation by JPL/NASA as delta differential one way range (DDOR) technique. Since precision of delay measurement of the DDOR is limited by bandwidth of spacecraft signal, long baseline is necessary for high angular resolution. We are trying to use phase delay to enable high delay resolution and high angular resolution. We report here an approach to reduce unknown ambiguities by connecting phase continuously in observation of NOZOMI, which was the first Japanese Mars mission. Spacecraft observation is one of good application of e-VLBI from two viewpoints. Firstly, data rate in a few tens of Mbps of VLBI observation, which is limited by bandwidth of spacecraft, is relatively easy for data transfer through the computer network. Secondly, quick turn around enabled by e-VLBI is a benefit for quick decision of orbit change in spacecraft navigation, since earlier orbit correction saves fuel of the spacecraft.

1. Introduction

Range and range rate (R&RR) measurement technique is mainly used for navigation of spacecraft in deep space. Since the range measurement is sensitive in direction of line of sight (LoS) and VLBI is sensitive in the plane perpendicular to the LoS, joint use of these two techniques enables enhancement of orbit determination of spacecraft. The JPL and NASA have been using delta differential one way range (DDOR) technique, which is a kind of VLBI observation with group delay, since 1980's[1]. Although precision of group delay measurement with spacecraft signal is limited in order of 1 ns by its bandwidth, which is up to several MHz whereas ten ps of precision is routinely achieved in standard geodetic VLBI observations of quasar by using several hundreds MHz of bandwidth. Relatively low delay resolution of group delay can be compensated by long baselines to achieve high angular resolution in spacecraft observation. Enabling to use phase delay of VLBI observation brings great benefit in spacecraft navigation. Phase delay has high precision of delay resolution by observation of tone signal. It can be generally applied for any spacecrafts, since tone signal can be generated without special equipments on spacecraft and up link operation from ground station. Main problem to be overcome in using phase delay is uncertainly of ambiguity of phase delay. Table 1 briefly summarizes the difference between group delay and phase delay measurements. Japanese space agency JAXA, NICT, and other Japanese institutes using VLBI

Table 1. Comparison of Group delay and Phase delay measurements in spacecraft observation

	Group Delay	Phase Delay
Delay Resolution	Not high ≥ 0.1 ns	High $\sim$ 10ps
Ambiguity problems	Basically no	Yes $(n \times f_{\mathrm{RF}}/c)$
Differential VLBI observation	Requirement to switching cycle time is not so severe, because group delay has no ambiguity.	Attention have to be paid in choice of switching cycle and reference radio source, because observation become useless if phase connections among scans are failed.
Requirement to spacecraft signal	Wide band signal	Only tone signal is enough
Current status	Used as DDOR by NASA	Under investigation

started collaboration to use VLBI technique for spacecraft navigation since 2000[4]. Currently we are trying both approaches phase delay and group delay, since each of these have merit and demerit, respectively. Result of phase delay observation of spacecraft NOZOMI is reported in this paper.

2. VLBI Observation of Spacecraft NOZOMI

Spacecraft NOZOMI performed two earth swingbys in December 2002 and June 2003. During this period, a series of VLBI observations of NOZOMI were performed to support orbit determination of the spacecraft. Most of Japanese VLBI related institutes which have X-band receivers and Canadian Algonquin observatory had joined in the observation. Figure 1 displays VLBI stations joined in VLBI observation of NOZOMI. Basically, NOZOMI was observed continuously to connect fringe phase safely for a long time.

3. Analysis Procedure and Result

Delay data measured by VLBI observations are passed to ISAS/JAXA and used for joint analysis with R&RR measurement data for orbit determination. Besides of that, astrometric analysis by using VLBI data has been performed and this is the subject of this paper. Astrometric analysis is based on least square parameter estimation with residual delay. A new VLBI delay model for Finite distance radio source [5] [6] was developed and used for spacecraft instead of standard VLBI delay model[3][2], since effect of curved wavefront is significant. The new VLBI delay model for finite distance radio source was implemented in modified venison of CALC9 and it was used for theoretical delay computation. Residual delay (Observed delay) - (Theoretical delay) was analyzed by least square method. Clock parameters, atmospheric parameters, and the NOZOMI's celestial coordinates $(\Delta\alpha, \Delta\delta)$ are estimated simultaneously. Uncertainty of ambiguity is the main problem in using phase delay. Our approach to this problem is connection of phase between scan to scan, because phase connection correspond to reducing number of unknown ambiguities thus reducing unknown parameters to reasonable number enables least square analysis with phase delay. Closure

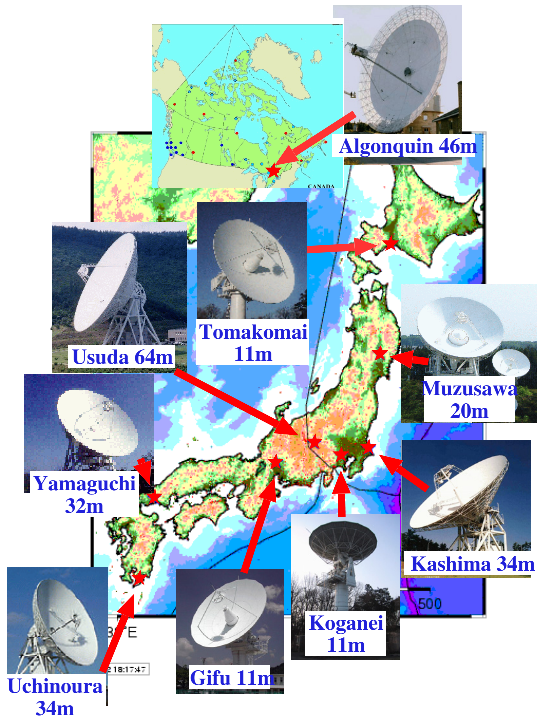

Figure 1. Most of Japanese domestic VLBI stations and Algonquin observatory had joined for NOZOMI VLBI observation with X-band receiver.

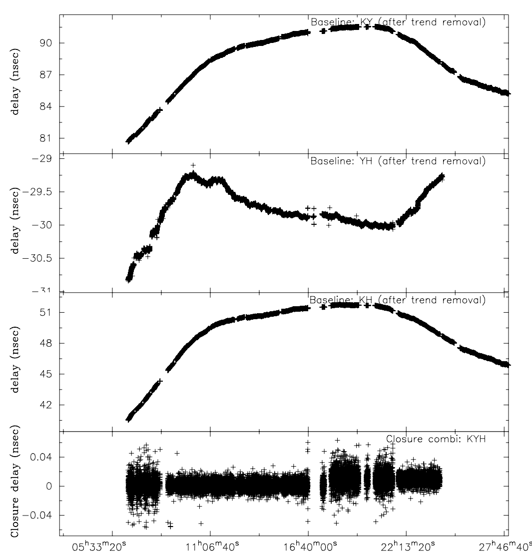

Figure 2. Phase delay and closure delay of KY, KH, and YH baselines in NOZOMI observation on 4th June 2003. Each character K,Y,and H represent Yamaguchi 32m, Gifu 11m, and Tomakomai 11m antenna, respectively.

relation is useful to support these phase connection procedure. Figure 2 shows an example of phase delay and closure delay of (Yamaguchi 32m)-(Gifu 11m)-(Tomakomai 11m) baselines in NOZOMI observation on 4th June 2003. NOZOMI was successfully observed more than 24 hours at 7 stations on this day, then source coordinates are accurately estimated. Figure 3 shows plot of NOZOMI's coordinates solutions. The trace of plot demonstrate that the estimated coordinates by VLBI converged to the consistent solution with conventional R&RR measurements as increasing the number of baselines used in the solution.

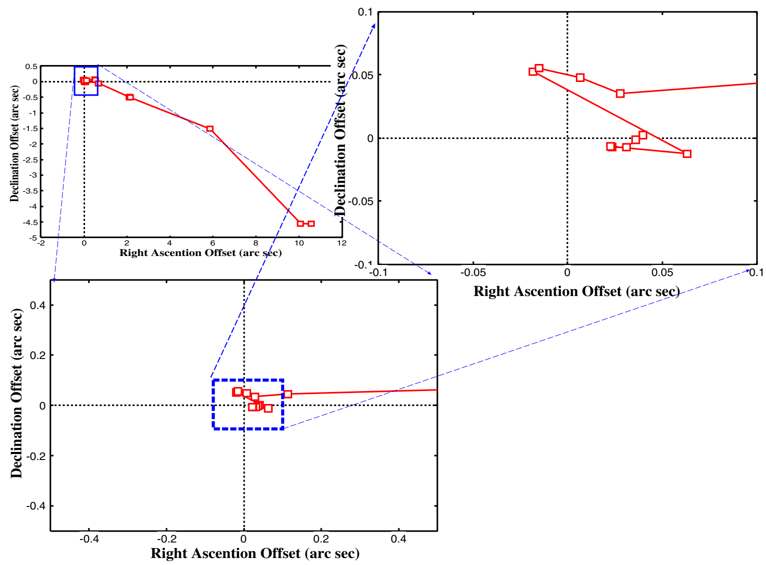

Figure 3. NOZOMI's geocentric celestial coordinates on 4th June 2003 estimated by phase delay on 21 baselines. Radio telescopes participated in this observation ware Kashima 34m, Usuda 64m, Yamaguchi 32m, Tsukuba 32m, Algonquin 46m, Gifu 11m, and Tomakomai 11m. The track of the plots indicates that the solutions of NOZOMI's coordinates converged to consistent solution with the R&RR data as increasing the number of baselines. The origin of the plot is the geocentric celestial coordinates of NOZOMI's orbit determined by conventional R&RR measurements.

4. Summary

For the aim to utilize VLBI for orbit determination of spacecraft, NOZOMI was observed by wide support of VLBI community. Phase delay data was analyzed by phase connection and least square method for estimation of the spacecraft coordinates. As the result of long time observation with multiple baselines and successful phase connection, astrometric coordinates of NOZOMI was estimated consistently with R&RR measurement results. However, since NOZOMI was observed continuously without switching to reference radio sources, atmospheric delay is not calibrated in the delay data. Consequently the atmospheric delay potentially couples with the geometrical delay and causes artificial offset in estimated coordinates. Differential VLBI observation by switching with nearest reference radio source is the next step to exclude potential error source of estimated coordinates, and is under investigation.

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A submillimeter wave VLBI network, Horizon Telescope

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Abstract

Imaging the surroundings of black hole is one of the ultimate goals of VLBI astronomy. SgrA*, the closest massive black hole, located at the Galactic center is the leading candidate for the observations because the SgrA* has the largest apparent Schwarzschild radius of more than $6\mu arcseconds$. We here show 230 GHz VLBI array at the Southern hemisphere has the good performance for imaging of the black hole in SgrA*. Also we note that it is already sufficient to image the black hole shadow with the present submillimeter radio techniques.

1. Introduction

Imaging black hole systems is one of the final goals in VLBI astronomy. SgrA*, the massive black hole at the Galactic center is the leading candidate for the research. Because SgrA* shows the largest apparent angular size among black hole candidates. The apparent Schwarzschild radius is estimated to 6μarcseconds from the mass ($2.6 \times 10^6 M_\odot$, Ghez et al. 2000) and the distance (8kpc). The corresponding shadow of black hole is about 30μarcseconds in diameter (Falcke et al. 2000). Recent observations indicate the mass of SgrA* is $3.7 - 4.1 \times 10^6 M_\odot$ (Schödel et al. 2002, Ghez et al. 2003). If accepted the new values, the size of the black hole shadow is more than 45μarcseconds in diameter. New findings of rapid flarings of SgrA* from a few hours to 30 minutes at radio, infrared, and x-ray emissions (Miyazaki et al. 2003, Zhao et al. 2004, Genzel et al. 2003., Baganoff et al. 2001, Goldwurm et al. 2003, Porquet et al. 2003) mean that the structure of the black hole system of SgrA* will also change rapidly. SgrA* has become an important source for investigating black hole environments. Previous centimeter to millimeter wave VLBI observations show that the scattering effects by surrounding plasma blurred the intrinsic image of SgrA* (Doeleman et al. 2001) and it is expected that sub-millimeter VLBI will unveil the true image. At the next section we show imaging performances of several VLBI array configurations for SgrA*.

2. Imaging Performances of Several Array Configurations

2.1. Array configurations

We test several array configurations as explained below. Namely array A is the same configuration as that of VLBA. Needless to say, the actual VLBA is only for below 86GHz observations. Array B includes the VLBA configuration plus a virtual station at Huancayo in Peru. The location of Huancayo is in lat.12.0375°S. in long. 75.2942°W., 3375-m in altitude. Array C is the Array B plus the ALMA position. Array D is the Array C plus the SEST position. Array E consists of the positions of five sub-millimeter telescopes, namely the SMA in Hawaii, the CARMA in California, the ALMA, the SEST in Chile and the virtual station at Huancayo in Peru. Array F is the inverse VLBA configuration. The antenna positions are inversed from the north to the south in latitude. Array G includes virtual 10 stations; 8 stations in the Andes mountains (Huancayo, ALMA, SEST, Cerro Murallon, Cotopaxi, Pico Cristobal, Maipo, and Araral) with Itapetinga in Brazil and SAAO position in South Africa. Array H is the Array G plus the SMA position and the CARMA position. Figure 1 shows the uv-coverages of these arrays for SgrA* at 230GHz. The uv-coverage of the array A is not good in north-south direction for observing low declination objects like SgrA* ($\delta = -30°$) (Fig. 2a). The array E has quite large but very sparse uv coverages (Fig. 2e). In comparison, other arrays show dense uv-coverages. We adopt the system temperatures 150 K, the 15 m antenna with efficiency 0.7 and recording bandwidth of 1 GHz with quantized efficiency of 0.7. Please be aware that the conditions of atmosphere are not considered in these simulations. We here assume the scattering effect is already negligible at 230GHz following the recent analysis of Bower et al (2004).

2.2. Image model for SgrA* at 230GHz

We used several model images. One is a Gaussian shape with central shadow (the HPBW of the Gaussian is 0.1mas in major axis and 0.08mas in minor axis, the position angle is 80°. The central brightness is removed as the shadow (elliptical shape with $30\mu arcseconds \times 24\mu arcseconds$). The adopted outer size follows the first 215GHz VLBI detections of SgrA* (Krichbaum et al. 1998). Another model is a standard disk and black hole shadow with $30\mu arcseconds$ in diameter viewed from almost edge-on. We also used ADAF disk models adapted to the spectrum of the SgrA*.

2.3. Resultant Images from Clean

We performed Clean imaging with the task IMAGR in AIPS (NRAO). The restoring beams are unified to the circular Gaussian with the HPBW of 20μarcseconds. Figure 2 shows the resultant images in case of a ADAF disk model calculated by Takahashi et al. (20004). Other two image cases are described in Miyoshi et. al (2004). The resultant images from the arrays A and E are not so good while other resultant images are very similar to the original image. The array E, a network of realistic sub-millimeter telescopes – SMA, CARMA, SEST, ALMA and Huancayo– does not show sufficient performance for the imaging. These results shows the excellent image is obtained from arrays 8000km in extent, 10 of stations. From the point of atmospheric conditions an array located at the Southern hemisphere is the best one for imaging the black hole of SgrA*.

3. Visibility Analysis

Fig. 3 shows visibility curves of three image models, (a) a simple Gaussian brightness without shadow, (b) a Gaussian with the shadow of $30\mu arcseconds(M_{BH} = 2.6 \times 10^6 M_\odot)$ and (c) a Gaussian with the shadow of $45\mu arcseconds(M_{BH} = 3.7 \times 10^6 M_\odot)$. For simplicity we used here point symmetric images. While a Gaussian brightness shows also a Gaussian visibility curve in the amplitude variations, if the shadow exits the visibility function has null value points at some projected baseline length. The null value positions changes with the size of shadow. From visibility amplitude function, we can distinguish whether the shadow exists or not. Further, because the null value points move according as the shadow size, we can estimate the shadow size, and the mass of black hole from the null value positions. If the image of SgrA* at 230GHz is really simple like this, visibility analysis will be sufficient to estimating the size and mass of SgrA* from small

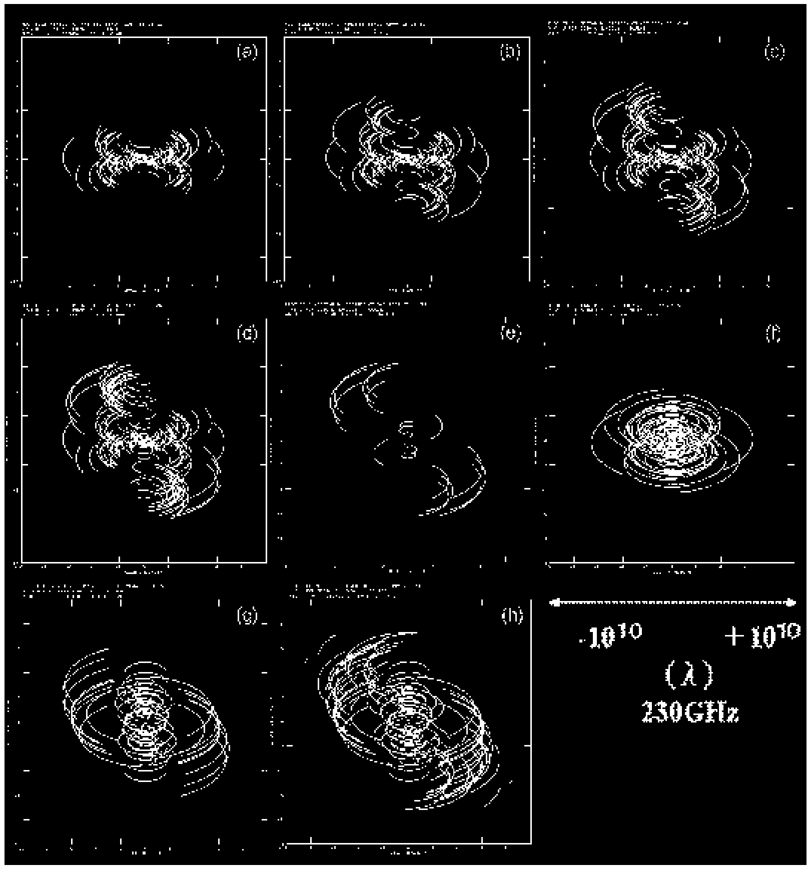

Figure 1. The uv Coverages of Several Array Configurations of SgrA* at 230GHz.

number of baselines.

4. Discussion

In order to get good image of SgrA* black hole, we need a array in Southern hemisphere like VLBA, namely about 10 stations and 8000km in its extent. We note below other aspects for the observing the black hole in SgrA*. As for sensitivity, there is no serious problem. Even the present level of VLBI and submillimeter radio technique gives us the sufficient sensitivity to measure such null points positions in Fig 3. For example, a baseline between two 15-m telescopes with efficiency

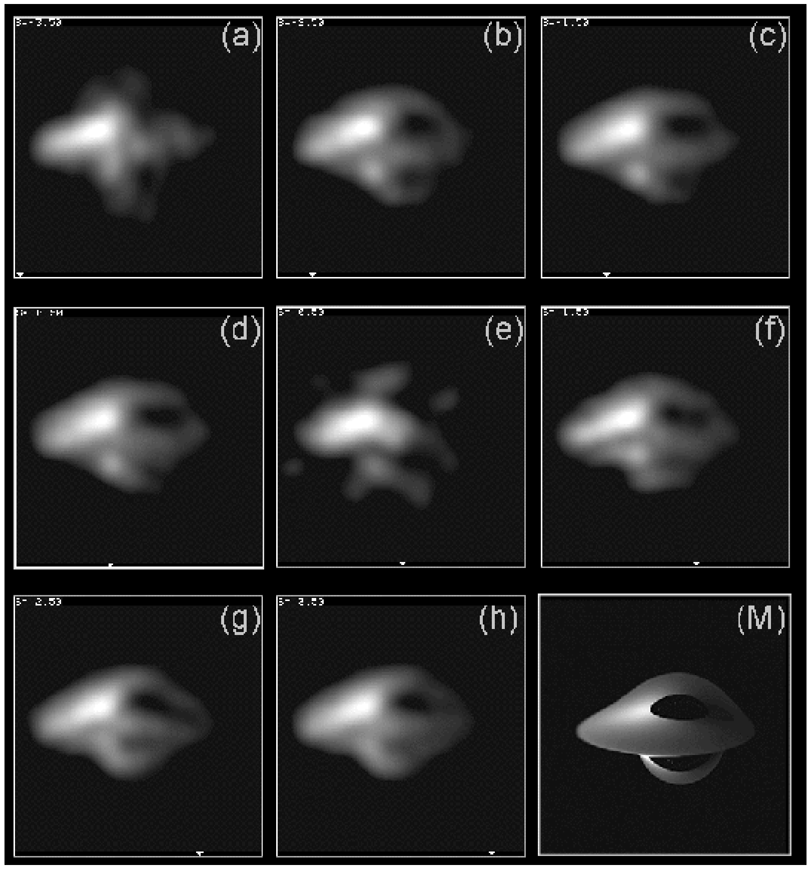

Figure 2. Resultant Images of SgrA* at 230GHz in case of a Kerr hole with ADAF disk model calculated from the observed spectra of SgrA*. The viewing angle is assumed to be 80°, almost edge-on. The span of each figure is $250\mu arcseconds$. From figure 2(a) to 2(h) we shows the results from each array while the figure 2(M) shows the original image model.

0.7, and system temperature 150 K, 1-GHz band width digital recording with quantized efficiency of 0.7, the 1σ rms noise level reaches 10 mJy with 100 seconds integration (The 3σ rms noise level is shown as horizontal red line in figure 5). If the accretion disk itself is optically thick at observing wavelength, the black hole shadow will not be seen. Can we observe the black hole shadow in radio wavelength? Takahashi (2004), however, shows that the black hole shadow of SgrA* is observable at 230GHz observations though the accretion disk is optically think at the

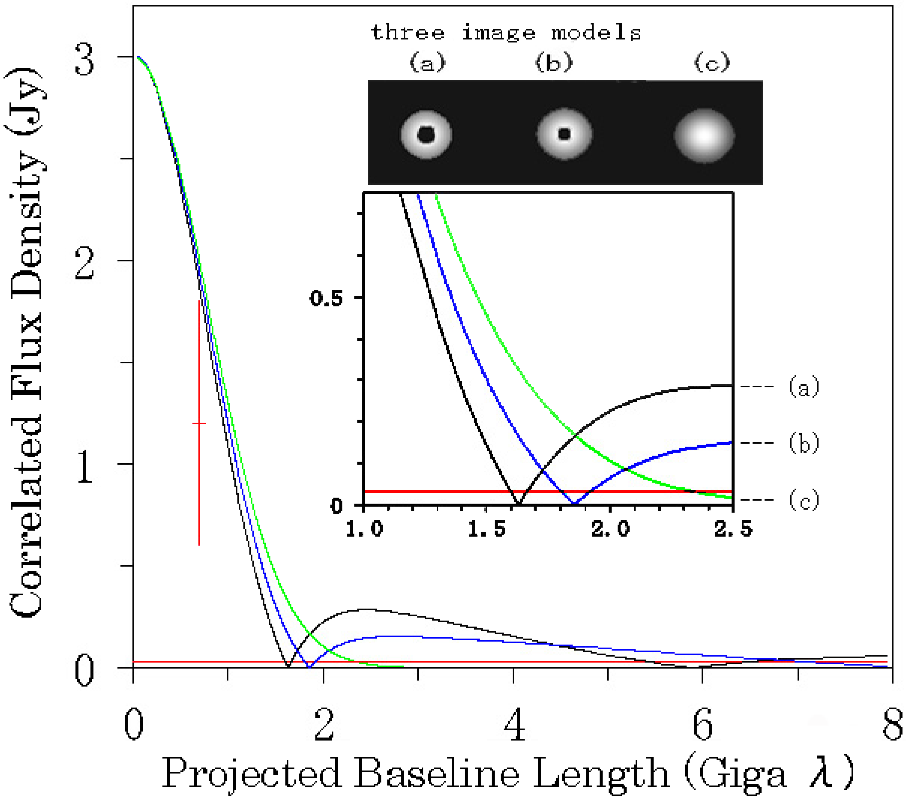

Figure 3. The visibility amplitude functions of three image models with projected baseline. (a) the case of $M_{BH} = 3.7 \times 10^6 M_\odot$, (b) the case of $M_{BH} = 2.6 \times 10^6 M_\odot$ and (c) the case with no black hole or the scattering effect is still dominant. The functions of (a) and (b) have null value points that suggest the real existence of central shadow. The 3σ noise level of present engineering performance is shown by red horizon line. The point with error bar is measured visibility by Krichbaum et al. (1998).

frequency (e.g. Fig. 1) as far as the accretion pattern is not spherical but axis symmetric. Recent observations of polarization of SgrA* suggest the disk is not ADAF but RIAF disk that is optically thin at 230GHz. One of remaining issues is the scattering effect by plasma. Recent analysis of Bower et al (2004) suggests that the effect is already negligible at 230GHz. The remaining issue for the observations is whether we have good observing site in the Southern hemisphere or not. In order to get long baselines we must put VLBI stations away from ALMA site. The separation should be a few hundreds km to a few thousands km. So we need site survey for submillimeter VLBI stations in the Southern hemisphere. We are planning to start the site survey at Peru in Andes. If the good sites are found, then we can unveil the black hole environments of SgrA* with a submillimeter VLBI array in the Southern hemisphere.

Acknowledgements

We would like to thank Mr. Oyama, Drs. Asada and Takahashi for helpful discussions.

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The e-VLBI in Chinese VLBI Network

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Abstract

VLBI is a very important part of the radio astronomical research in China. The Chinese VLBI Network (CVN) has started to create the e-VLBI technology to increase his own facility for high resolution radio astronomy. The e-VLBI station equipment, communication system, data processor and experiments in CVN would be introduced in this paper. The near real time VLBI system used by Chinese Lunar Project is reported in briefly.

Table 1. Main Specification of Chinese VLBI stations

Name	Location	Antenna diameter (m)	Bands (GHz)	VLBI Terminals	Network Connect (Data Rate)	Available
Sheshan	Near Shanghai	25	0.3, 1.6, 2.3, 5.0, 8.4, 22	VLBA, MKIV, S2	No(1)	1987
Nanshan	Near Urumqi, Xinjiang Prov.	25	0.3, 1.6, 2.3, 5.0, 8.4, 22	MKIV, K4	2Mbps(2)	1994
Mobile VLBI	Kunming, Yunnan Prov.	3	2.3, 8.4	S2, MKIV	2Mbps(2)	1999
Kunming	Kunming, Yunnan Prov.	40	2.3, 8.4	MKIV, MKV	2Mbps(2)	2006
Miyun	Near Beijing	50	2.3, 8.4	MKIV, MKV	No(2)	2006

(1) 100Mbps data rate network connect will be created in year 2005
(2) 10Mbps data rate network connect will be upgraded before end of 2006

1. Introduction

The VLBI Network in China is a very important part of the Chinese radio astronomical research. There are two radio telescopes which working for VLBI observation in China. One is near Shanghai and the other is near Urumqi. The diameter of both antennas is 25 meters. They are the members of the European VLBI Network (EVN), International VLBI Service for Geodesy and Astrometry (IVS). There is a mobile VLBI station which currently located in Kunming, south of China. The mobile VLBI station has 3 meters diameter antenna and MK4 VLBI format and disk array recorder. There are two new antennas will be constructed in Miyun, near Beijing and in Kunming, south of China. The VLBI facilities for both antennas are planed. Since 1995 a two-station Correlator was started to develop. The main Specifications of Chinese VLBI stations are illustrated in table 1. Except Sheshan and Miyun station, there are network connect with these VLBI stations now.

2. The development of e-VLBI facilities in China

Since year 2003, the Chinese VLBI network started to make some e-VLBI observation experiments to obtain the experience of e-VLBI technologies. We have developed some station equipment such as DBBC, MK4 formatter, Disk array and the software correlator which used for fringe test and prepare for e-VLBI data processing.

2.1. The DBBC

There are many advantages of the digital base-band converter. The BBC is key equipment for VLBI station. With development of LSI, the digital base-band converter shows more advantages compare with tradition (analog) base-band converter. We have cooperation with IRA to develop a digital base-band converter, which named as MiniDBBC. The general characteristics are following.

General Features of MiniDBBC:

1. Two IF, total bandwidth : 256 MHz
2. 2 Channel / IF's
3. sampling clock 256MHz
4. Channel bandwidth 500 KHz, 1-4-8 MHz selectable
5. Tuning step 50 KHz
6. Using fully re-configurable FPGA Core Modules
7. Interface for MK4 formatter
8. Total power measurement capability
9. Digital to analog converter monitor output
10. Digital AGC with external PC control

2.2. PC-based disk array system

We finished the development of our PC-based disk array system in begin of year 2003. There are more advantages to work with disk array. The reason to develop the PC-based disk array system was the problem with our tape playback system. The main targets for development of disk array are:

1. Low cost
2. As simple as possible to reduce the hardware interfaces to port VLBI data to and from the industry standard PCI bus.

3. Use Linux with standard compiler and development tools.
4. Record Mk4 data and include interfaces to Mk4 formatter and correlator, VSI format is in plan
5. Prepare for e-VLBI, used as a huge FIFO device, to solve the network delay by e-VLBI experiment. 4 GB memory should be good for 32 seconds data stream @ 1Gbps

2.3. Software correlator

We have a Matlab version Mk4 data format correlation software used for fringe checking, fringe search by satellite observation, delay & DOD (Differential of One-way Doppler) frequency measurement by observation the special narrow band satellite downlink telemetry signals. Since begin of this year, we started to write VLBI correlator software in C computer language to support the orbit determination of the Chinese lunar satellite (as backup of the hardware correlator).

2.4. The real time hardware correlator

Figure 1 shows a diagram of 5 stations real time correlator for Chinese lunar project (CE-1). In this project will use 4 stations VLBI network to make orbiting determine of lunar satellite. For data reduction we need a real time correlator. The data rate of correlator is 10Mbps / station in real time mode, and 256Mbps / station for post processing. The wide bandwidth data will be writing to disk array and playback by correlator. The correlator used FPGA technologies for playback interface (include deformator and track recover function), FFT, MAC and the control logic. The virtex II from XILINX is power enough to acceptance the station electronics and baseline electronics. It could remarkably reduce the cable connect compare with old hardware correlator. The whole 5 stations real time correlator will use only several Virtex II chips. The hardware of correlator will be included in 2 or 3 PCBs. The correlator has fringe searcher and P-cal access function. The PC-based disk array will be used as the playback system for correlator. There are maximal 4GB memory should be mounted in these PCs. The 4GB memory could take on a huge FIFO, for smoothly the data stream from disk array and from network. The commercial PC board AD7300A is used in these PCs, as a high data rate interface between PC memory and playback interface. The data rate of interface is 10Mbps for real time correlation and 256Mbps for post correlation. The data streams are control by playback interface. The FFT and MAC logics of one channel of 5 stations could be configured in one FPGA chip. Compare with old hardware correlator, this design could reduce many connect cables and will increase the system reliability. The long term accumulate function is operated in a normal PC. In these PC, it will do fringe finding and checking. The models calculate and the system monitor will be doing in other PC, which named CCC. The model parameter will be send to FFT chip and PBI chip via Master control board.

2.5. Observation experiments

After we have our PC-based disk array, via FTP, the fringe checking is easy to do during the VLBI observatory. In May 2003, used our PC-based disk array, via FTP, we obtain first successful e-VLBI fringe test between Urumqi and Shanghai.

Figure 2 shows the narrow band observation in Chinese VLBI network. Right figure shows the

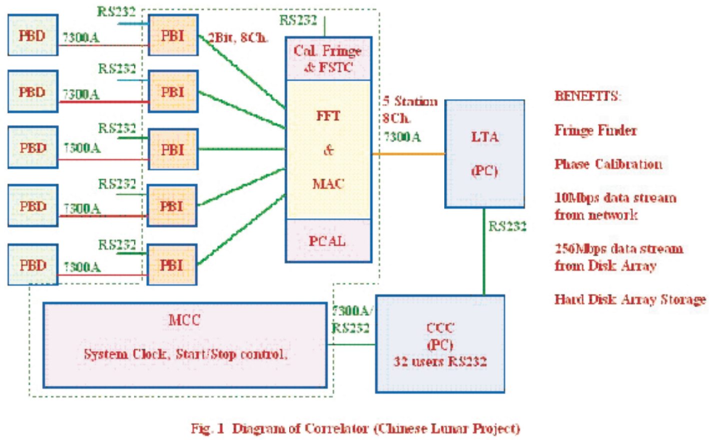

Figure 1. Diagram of Correlator (Chinese Lunar Project).

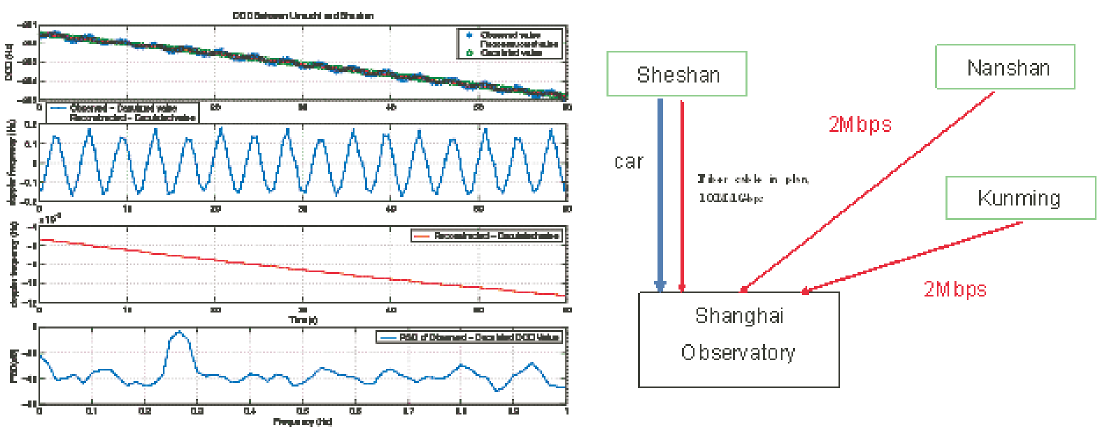

Figure 2. Narrow band observation, left results, right data transport.

data transfer from station to correlator. There is network connecting from Nanshan and Kunming to Shanghai Observatory, but there is no network connecting from Sheshan to city Shanghai. The data transfer, from Sheshan to correlator need 30 minutes with car. The left figure shows some results of satellite VLBI narrow band observation. The result shows the spin effect of satellite.

In Sept. 22, 2004 UTC, we have single baseline narrow band observation. The target of satellite is Smart-1, which is an ESA lunar project and was launched at one year ago. During observation, the distance between Smart-1 and the earth is more than 280,000Km. Used 0.5 second data via FTP for fringe checking. With these data, the delay accuracy is 0.6ns and delay rate accuracy is 1.8ps/s.

2.6. The network connect

There are four VLBI stations in Chinese VLBI network. They are Sheshan (near Shanghai) station, Urumqi station, Kunming station and Miyun (near Beijing) station. There are fiber connect to Urumqi station and Kunming station. The data rate is 2Mbps for each station. There is no network connect to Sheshan station and Miyun station. There is a plan to create a network connect to Sheshan station and Miyun station. The network data rate for four stations will be increased to 10Mbps before the end of 2006.

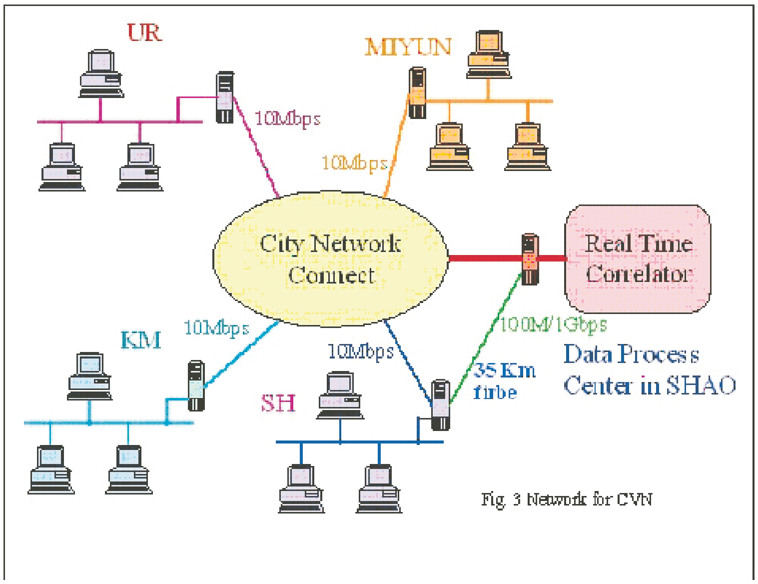

Figure 3. Network for CVN.

3. Conclusion

CVN will have four VLBI stations in not longer time. We prepare to develop a five-station real time correlator. There is a plan to create a network to connect four stations to correlator. The network data rate for four stations will be increased to 10Mbps before the end of 2006.

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Status of VLBI and e-VLBI in Urumqi Astronomical Observatory

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Abstract

The Nanshan 25m radio telescope is run by Urumqi Astronomical Observatory (UAO), NAOC, Chinese Academy of Sciences (CAS). It is one of the five main astronomical facilities of Chinese National Astronomical Observatories (NAOC). The Nanshan VLBI station is a member of the EVN, IVS, and APT. It joins many VLBI observations every year. The Local Network was built in August 2002 and the optical fiber lines were built in October 2003. Recently, the backend system was upgraded to MK5A. This paper introduces the status of VLBI and e-VLBI in UAO.

1. Introduction

The telescope is located about 70 km south of Urumqi at longitude 87.2 degrees East, latitude 43.3 degrees North and altitude 2080 meters above sea level. It has been in operation for VLBI observation since 1993 and opened on October 1994 during the APT meeting in Urumqi. During 10 years operation, the telescope is continuous built new and upgrade the system, joined VLBI and single-dish observations. Now, the Local Network and optical fiber lines were built, the MK5 VLBI system was completed. So we hope the e-VLBI observations are operated in future.

2. VLBI system

2.1. Antenna

Diameter: 25 meters
Antenna type: Cassegrain reflector
Seat-rack type: Azimuth-pitching ring
Point precision: $15''$ (rms)
Rolling range: Azimuth $-270°$ to $+270°$; Elevation $4°$ to $89°$
Maximum rolling speed: Azimuth $1°$/sec; Elevation $0.5°$/sec

2.2. Receiver

Seven bands for VLBI observations are available at Nanshan 25m radio telescope: 92cm, 30cm, 18cm, 13cm, 6cm, 3.6cm and 1.3cm.The parameters of the receivers are listed in Table 1.

The 18cm dual-polarization and cryogenic receiver system was installed in 2002. The performance of 18cm receiver is one of the best system in EVN.

A new 30cm room temperature receiver with new feed has been installed in February, 2004. The VLBI test observation was done on February. The fringe had gotten.

A new 6cm dual-polarization, cryogenic receiver with new feed horn was installed in August, 2004. The system noise temperature is about 20K, it is one of the most sensitive receiver in the world.

Table 1. Receivers of Nashan Station

Band	Bandwidth (MHz)	Eff. (%)	Type	Polarization	Tsys(K)
92cm	314−340	30	Room Temp	LCP	150
30cm	850−1150	35	Room Temp	LCP	140
18cm	1400−1740	49	Cryogenic	L/RCP	22
13cm	2150−2450	48	Room Temp	RCP	100
6cm	4500−5100	55	Cryogenic	L/RCP	20
3.6cm	8200−8600	50	Cryogenic	RCP	45
1.3cm	22200−24500	35	Cryogenic	LCP	180

2.3. Terminal

The terminal systems include MK2,MK4 and MK5A.

The MK2 system takes part in observations of LFVN (Russian). The MK2 system includes: MK2 digital quality analyzer, MK2 formatter, MK2 IF to video converter, tape recorder etc.

The MK4 system was upgraded at Nanshan VLBI Station in 2000. The MK4 system includes: IF to video converter, decoder, formatter, TTY distributor 5MHz distributor, tape recorder etc.

The new MK5A system by establish at Nanshan VLBI Station in March,2004. The test of the equipment and the first VLBI experiment with MK5A system recorded in May. The present status of the MK5A system looks fine. Many tests were done with good results. The new MK5A system is equipped with 8 disks of 120 GB each. The equipment including: FS computer, Formatter, IF to video converter, recorder computer etc.

3. VLBI observations

Since the first observation in 1994, Nanshan has contributed thousands of hours observation time for ENV, IVS, LFVN. The VLBI observations at Nanshan was greatly improved in 2003. As shown in Table2 altogether we contributed 635 hours telescope time for VLBI in 2003, most of them were successful. UAO staff also obtained several observation times from EVN for AGN and CSS studies.

Table 2. VLBI Observations at Nanshan in 2003

VLBI Network	Hours
EVN	270
LFVN	48
IVS	222
Nanshan-Sheshan	95
total	635

4. e-VLBI

The network is the base of e-VLBI. In Nanshan VLBI station, the local area network (LAN) had built in August 2002.The data transfer rate is 100Mbps in the LAN. But we had to use dial-up connect to internet, the data transfer rate is too slow. The optical-fiber line (for data transfer) was operated in October 2003. We currently have the 2Mbps bandwidth connection to the internet, and is planning to upgrade it to 10Mbps or 100Mbps in the future.

Presently the e-VLBI system at Nanshan is built towards the purpose of Chinese VLBI network, i.e. the near real time VLBI system. Once the network connection is improved, e-VLBI will be realistic for Nanshan. We can contribute more telescope time for e-VLBI observation then.

E-LFVN - An Internet Based VLBI Network

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Abstract

A narrow band e-VLBI system is operating as a part of the LFVN (Low Frequency VLBI Network) activity taking advantages by the relatively small portion of band necessary in a certain class of radioastronomy observations.
Data are acquired using a simple dedicate terminal and recorded on disk. The maximum recorded signal band is 48 MHz wide, flexibly scalable up to few kilohertz and then with the concrete possibility to transfer the full amount or portion of it in near real time to a correlation point, using the standard Internet connection, when narrow band acquisitions are appropriate.
Radar, spectral lines, low frequency, spacecraft navigation observations can benefit from this inexpensive solution in those stations where large antennas and sensitive receivers are available, and where is still missing the possibility to be aligned with standard VLBI terminals, giving then yet the possibility to perform radio astronomy research.
The terminal is at present placed in Noto (Italy), Bear Lakes (Russia), Urumqi (China), Simeiz (Ukraine), Evpatoria (Ukraine) and is going to be expanded with a digital baseband backend system.
During 2003 and 2004 these terminals and method have been succesfully tested in real experiments having as targets debris, asteroids, planets.
A further improvement will be to add station based pre-processing steps to optimize the data transfer.

1. NRTV VLBI System

The NRTV Internet based acquisition, transfer and correlation system has been used starting with the 2003 in different radar sessions, and it has been proved to be flexible enough for getting information even during the observation period. The system is based on a 1 or 2 bit sampling stage at base band level, with further data packing and recording through a dedicated board. Data are recorded as files that are then collected to a processing facility, now placed in Noto.
During radar observations echo signals in the different stations are detected in order to confirm goodness of operations and proper doppler estimation. Further Internet data transfer is the only method to link stations, without any need for disks shipment.

An upgrade is planned for 2005, when a fully digital backend system will be added to the front part of the acquisition chain. Such system, named E-DBBC, is able to feed the 48 MHz required

Figure 1. The entire acquisition terminal is shown: from the left side, an external Firewire/USB2 disk, NRTV Box, a commercial PCI board.

by the recording system in a IF range coming from the receiver between 80 and 128 MHz, and is mainly set and used via network. Tuning and filtering can handle bandwidth from 500 KHz up to 16 MHz, with a tuning step of 50 KHz. Moreover a GPS receiver will be integrated with the system in order to simplify the synchronization, now assured by station 1PPS and NTP servers.

A software correlator is at present adopted, sharing more processes among different PC platform, baseline dependent. A simplification and correlation time reduction will come from the introduction of an initial preprocessing in the acquisition station before sending data to the correlation point. This can allow to take into account the restricted portion of band interested by the detected signal in those situations when a quasi-monochromatic tone has to be processed.
The preprocessing step is then performed within the acquisition computer taking into account an input file cointaining the a-priori expected frequency of the echo signals. A complex FFT is performed with high frequency resolution (0.015 Hz) and only data around the signal are kept to be transferred for correlation. The total data reduction can achieve a factor of 1000:1 depending on the echo frequency spread.

2. Low Frequency VLBI Network Project

The LFVN project was started in 1996, having the purpose to arrange the international VLBI cooperation with participation of former Soviet Union radio telescopes. During the project 18 VLBI experiments were carried out using various combinations of radio telescopes and correlators

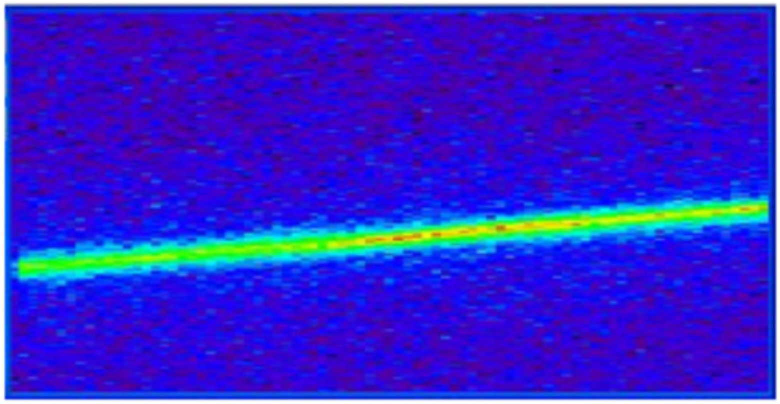

Figure 2. The spectra in time show the echo of the radar signal transmitted by Evpatoria, reflected by Mars, received in Noto. Frequency carrier was 5010.024 MHz, receiving LO was 5010.000 MHz. Vertical axis 238037,11-262329,11 Hz, horizontal axis day 207/208-time 2304-0025

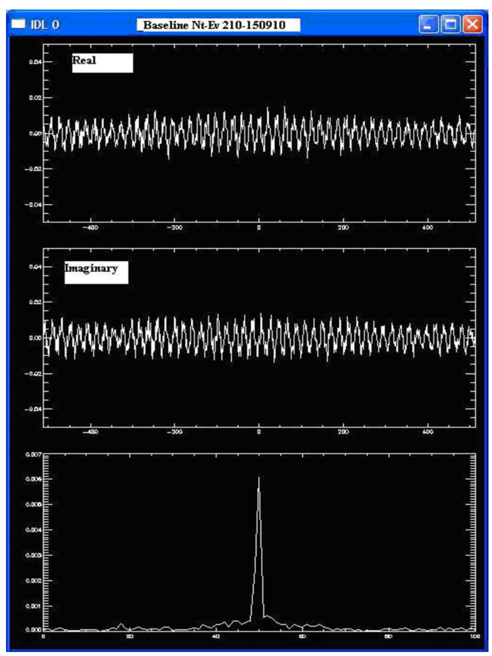

Figure 3. Cross-correlation detected on July 2004 by the NRTV correlator in Noto after data transfer from Evpatoria radiotelescope. Signal detected is the echo from a space debris.

in Canada, China, Urumqi, England, India, Italy, Japan, Latvia, Poland, Russia, South Africa, Ukraine, and USA.

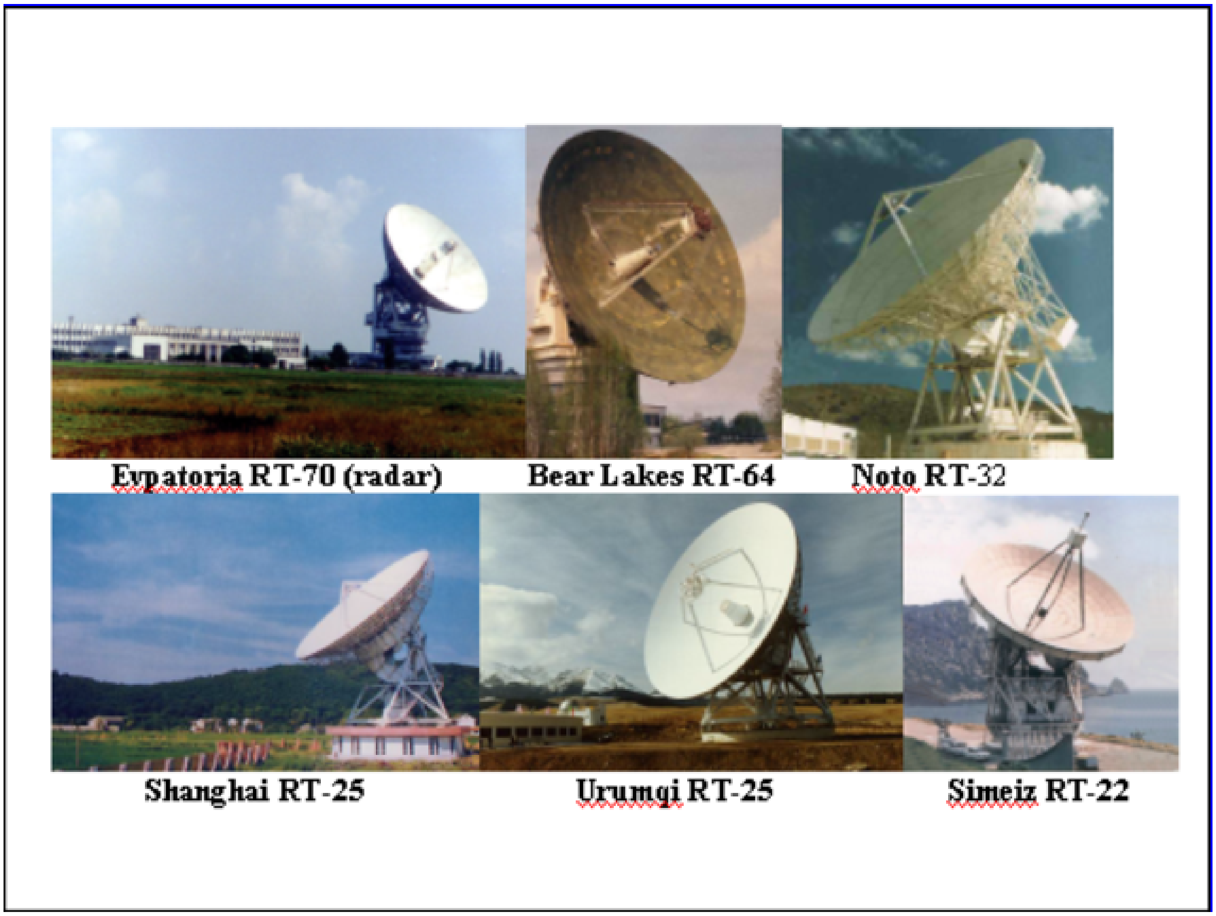

Figure 4. Some Radiotelescopes involved in the LFVN Project

Main directions of LFVN activity are:
- Learning the VLBI radar method, combination of classic radar and VLBI: study of short-periodic variation of proper rotation for the Earth group planets, improving the orbits of asteroids crossing the Earth orbit, measuring the space debris population at geo-stationary and high-elliptic orbits;
- Developing new methods of the solar investigations: mapping the solar wind irregularities, measuring the spatially-temporary structure of solar spikes;
- Mastering the near-real time differential VLBI technique for determining the satellite and deep space mission coordinates;
- Traditional VLBI astronomic observations as AGN and OH-maser imaging and investigation of active stars and stellar coronae structures.

Acknowledgements

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High Performance PC Based Gigabit VLBI System

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Abstract

The performance of personal computer (PC) is improving dramatically in recent years. Compare the performance of software correlation using such PCs to that of hardware correlation is nearly equal now. Replacing magnetic tapes and hardware correlator with disk-arrays and the PC cluster are reasonable choices. The VLBI group of National Institute of Information and Communications Technology (NICT) has researched the PC based VLBI system for several years. Performance of the recording speed of the PC based system reached to 2Gbps and correlation speed reached to 1Gbps.

1. PC Based VLBI Observation System

The PC based VLBI system is based on the Versatile Scientific Interface (VSI). It is composed of inexpensive parts of the PC excluding A/D samplers and the VSI data capture board plugged into a 64bit/66MHz PCI slot [Kimura et al., 2002]. NICT have developed two VSI compatible A/D samplers named ADS1000 [Nakajima et al., 2001] and ADS2000. The ADS1000 is mainly used for astronomical VLBI observation with ultra-wide-band IF, and the ADS2000 is mainly used for geodetic VLBI observation with 16-channel IFs. Sampling mode and data clock of those samplers are shown in Table 1 and 2.

Table 1. Sampling mode and VSI data clock of the ADS1000

Mode	Data rate	VSI clock
1024Msps/2bit	2048Mbps	64MHz
1024Msps/1bit	1024Mbps	32MHz
512Msps/2bit	1024Mbps	32MHz

Table 2. Sampling mode and VSI data clock of the ADS2000

Mode	Data rate	VSI clock
64Msps/2bit/16ch	2048Mbps	64MHz
64Msps/1bit/16ch	1024Mbps	32MHz
32Msps/2bit/16ch	1024Mbps	32MHz
16Msps/2bit/16ch	512Mbps	16MHz

The VSI data stream from those samplers is transmitted to the data capture board equipped in PC. The board sends the VSI data to the PCI bus working at 64bit/66MHz. The VLBI data can be transmitted in PC's memory continuously without any CPU load by DMA. The 1024MByte of continuous physical memory is secured for steady DMA operation. The data stored in memory can be used for recording in a disk array, processing for autocorrelation and transporting to another stations for real time correlation via Internet. Using two gigabit ether ports, the most data of 2Gbps-VLBI stream can be transmitted to the correlation site. It is possible to record 12 hours 1Gbps VLBI data in a disk array system. The record time can be extended by using two or more disk arrays easily. The view of the current PC-VLBI system for VLBI observation is shown in Figure 1.

Figure 1. There are a removal disk unit which has the hot-plug function, previously described ADS1000, the disk array with fourteen independent 400GB serial ATA drives and 1U PC server equipped VSI2000-DIM board.

2. PC Based VLBI Correlation System

The correlation of VLBI data is processed by software using CPUs [Kimura et al., 2002]. The multi baseline processing is necessary and indispensable to use it for VLBI standard observations. The XF type software correlation is very fast only one baseline processing with small lag number. Almost all operations of the XF or FX types correlation are composed of bit operations or floating point operations. As for recent CPUs, the bit processing operations have been hardly optimized. But, the floating point operation have been great optimized such as a vector processing technology. It is thought that this tendency will continue. In the future, the correlation speed that exceeds 10Gsps will become possible by future CPUs that adopts the multi-core technology such as the CELL processor developed by IBM and SECI. The performance of CPU becoming a bottleneck will not happen for several years in the future. Currently, the software correlator works by not only Intel and AMD processors but also PowerPC processors. Because of the operation of multiply accumulate, basically two vectors are multiplied together and added to a third vector, the PowerPC processor is two times faster than Intel processor such operation. A Pentium 4 requires minimum of two operations to complete this algorithm, one vector multiply and one vector addition. A lot of accumulate after multiply is included in the FX type correlation. Above reason, the rack-mount cluster PCs each having two IBM PowerPC 970FX processors rated at 2GHz have been constructed for software correlation in NICT 2. The distributed processing technique is described [Kimura et al., 2002]. The current performance of software correlation with 2bit sampled data is shown in Figure 3. This result corresponds with expected performance described previous report using some PCs [Kimura et al., 2003].

Figure 2. The cluster PCs and disk arrays are set up on the lower half of the rack.

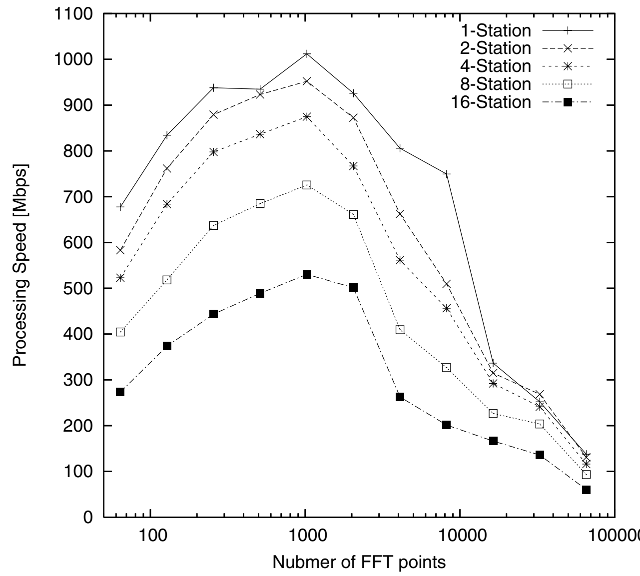

Figure 3. Result of the performance test: The low efficiency in the small FFT points area is due to overheads of function calls. The low efficiency in the large FFT points area is due to cache misses in the FFT process.

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VLBI Technology Development Center (TDC) at NICT is supposed

1) to develop new observation techniques and new systems for advanced Earth's rotation observations by VLBI and other space techniques,
2) to promote research in Earth rotation using VLBI,
3) to distribute new VLBI technology,
4) to contribute the standardization of VLBI interface, and
5) to deploy the real-time VLBI technique.

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